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PROBABILITIES OF FINANCIAL RETURNS FROM SOUTHERN PINE TIMBER GROWING

April 2, 1973

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FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

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Clark Row

Chapter 1

INTRODUCTION

Since the 1950's, a renewed southern pine timber resource has fostered rapid expansion of pulp and paper production, a new softwood plywood industry, and a comeback for lumber manufacturing. Output of softwood timber from the South has grown from 3.1 billion cubic feet in 1952 to 4.0 billion cubic feet in 1970. This sustained increase reversed a decline in timber output that had continued since the old-growth lumber boom at the turn of the century.

The causes of this remarkable and virtually unprecedented renewal of a major resource have been varied. Part of the regrowth has been unintentional. Natural regeneration of cutover forest lands and reversion of idle agricultural land to forest has restocked a large portion of the region's 200 million acres of forest land. Restocking and growth has been helped, or more accurately permitted, by expansion of public protection programs, especially for wildfire control. Some of the renewal has occurred as a result of management efforts and

investments on the part of all ownership groups.

Continued expansion of the southern timber supply is of major importance nationally, regionally, and locally. Of the major softwood producing regions of the U.S., the South alone has the potential for significant increases in growth and removals. In the West, softwood supply from private lands will almost surely decline in coming decades, and most public forest lands are now producing at sustained yield capacity (USDA Forest Service, 1965). Regionally, softwood timber industries have played a major role in the continuing expansion of employment and income (Kaiser and Dutrow, 1971). Forest products are the second largest class of outputs that the region produces, directly employing 11 percent of the region's manufacturing labor force. In many local areas, timber products are the dominant items in the economic export base.

Despite the resurgence of timber inventories[1/] and output, both public and industry resource analysts are concerned about the adequacy of the resource base for continued expansion (USDA Forest Service, 1965; Southern Forest Resources Committee, 1969). The pressing question is the extent to which timber removals can be increased. And in the long run this also implies the extent to which timber growth can be raised. Since little unstocked forest land remains and the rate of abandonment of agricultural land has slowed, future growth increases cannot come from expanded acreage. The only apparent source is intensification of management of presently forested areas.

1/ Certain terms, such as timber inventory used here, are employed in a more technical meaning than in ordinary usage. They are defined in Appendix 1.

Surveys of forest resources[2/] in each of the southern states show:

1. Individuals, each holding from a few acres to several thousand, own the largest share of forest land--73 percent in 1970. Though individual ownerships produce most of the timber supply, net growth per acre--42 cubic feet a year on the average--is substantially lower than on other ownerships. By and large, relatively little conscious forest management or investment is being made in these lands. As yet programs of public assistance to forest owners have had limited impact on management levels.

2. By aggressive land acquisition and leasing policies, forest industries and other large corporate ownerships are gradually increasing their share of southern forest lands. They now own 18 percent and lease another 5 percent. On this land the intensity of management is substantially higher than on individual ownerships or public lands. This has resulted in increased rates of net growth--54 cubic feet a year--and rapid accumulation of timber growing stock inventories. The effects are beginning to show in rising volumes of timber coming from forest industry land.

3. Public owners, particularly the U.S. Forest Service, have conservative management policies. These have resulted in high inventory levels, high net growth rates, but low rates of harvest. Present policies do not suggest greatly increased harvest can be expected from these limited areas.

2/ The basic source of U.S. forest area, inventory, and output statistics is the USDA Forest Service's Forest Survey. The forest resources in each State are resurveyed in rotation. The statistics have been updated to 1952 in Timber Resources in America's Future (1958), and to 1962 in Timber Trends in the United States (1965), A forthcoming study based on 1970 data is tentatively titled Outlook for Timber in the United States.

Though forest industry lands will continue to increase output, it is clear that reaching levels of output that approach the region's potential will require substantially improved levels of management on individual ownerships. Therefore, it is necessary to determine why individual ownership management is low, and more importantly, the extent to which intensifying management is economic.

Some individual owners already practice relatively intensive forest management. Requests for technical assistance from state forestry agencies continue to grow, and a sizeable portion of the clientele of consulting foresters are owners of medium sized tracts (Pleasanton, 1967). Nevertheless the number of owners and proportion of forest area held by individual owners under reasonably intensive levels of management continues to be small. In particular, few small owners appear willing to invest their own funds, or to borrow using land as collateral to increase forest productivity (Siegel, 1972).

A number of factors appear to have some influence, but singly or in combination do not explain the major differences in level of land management intensity among ownership classes. These are:

1. Ignorance of the opportunities to improve forest productivity. In most areas of the south, both public and private forestry organizations have had widespread publicity and educational campaigns to promote improved forest management for several decades. In most counties, the Agricultural Conservation Payment system--and formerly the Soil Bank--have included provisions for forestry activities. The existence of active markets for sawtimber and pulpwood--and often the approximate going price--are widely known. While most landowners may not know specifically what treatments may be applicable to their land, or how

to accomplish them, a large fraction appear to be aware that improved management is feasible on most forest land. For one reason or another, a large number do not believe that either improved timber growing management is economic for their holdings, that it is sufficiently worthwhile, or that it is compatible with their other objectives.

2. Productivity of individual ownerships. The average productivity of forest land in individual ownerships is only slightly below that of industry land. A number of limited analyses of average costs and returns of forest management show that many forest management practices have excellent to moderate returns (Worrell, 1956; Yoho and Fasick, 1965; Anderson 1966; Anderson and Guttenberg, 1971).

3. Special advantages for forest industries to manage lands. One traditional reason for lumber and pulp and paper firms to intensify management is to secure supplies of raw materials for large fixed investments in pulp and paper, and to a lesser extent for lumber and plywood mills. Though this is undoubtedly a factor, similar mills in the North and West do not invest with the same intensity in surrounding timbersheds.

What is seldom questioned, however, is whether intensification of timber growing activities is economically rewarding for the entire range of production opportunities, tract sizes, and owner objectives. And in particular, are there factors related to size of tract, uncertainty of returns, and income tax treatment that mitigate against individual owners of small and medium sized tracts?

An answer to these questions requires more detailed and extensive economic analysis of the potential returns from southern pine timber growing than has previously been attempted. Special attention must be

given to the following questions:

1. What are expected before and after-tax financial returns from various levels of management and investment in growing timber in a range of situations in the South?

2. How does tract size affect financial returns, and are the effects caused by differences in feasible technology, costs, output prices, or tax policies?

3. What is the risk and uncertainty of returns, and how does size of ownership affect them? Are risk and uncertainty major deterrents for small owners?

4. Do answers to the above questions suggest changes in programs and policies of federal and state agencies with responsibility to promote improved forest practices and economic development?

Possible approaches to answering these questions are limited. Long production periods and lack of longitudinal records preclude direct statistical estimation of financial returns. Realistic models of timber growing situation contain too many variables and relationships for direct analytic solutions. Restrictive assumptions sharply limit the usefulness of linear and dynamic programming for small ownerships or single timber stands (Kidd, Thompson, Hoepner, 1966, Schreuder, 1968).

The approach this study takes is that of stochastic simulation. A specially designed computer program can evaluate numerous Monte-Carlo simulations of a series of management levels of typical timber growing opportunities. The resultant distribution of rates of return or equivalent net incomes per acre will indicate probabilities of financial returns to timber growing. Analysis of the mean expected returns and their variances will employ the concepts of the economics of uncertainty

variously called Markowitz theory, portfolio theory, or mean-variance analysis.

In effect this approach embodies a mathematical model of timber production in a computer routine that estimates the outcomes of trials using sets of initial data and random variations. Thus the "model" of the complex real system can be used to perform experiments that are otherwise impossible or infeasible. This procedure has other advantages: (a) complex internal interactions can be studied in the context of a realistic situation, (b) experimentation with a model may lead to easier and more comprehensive understanding than observations from the real situation itself, (c) lack of knowledge or deficiencies of data are often revealed by simulation trials, (d) simulations may be used to predict consequences of real experiments or practices and reduce risks of failure.

The dynamic, stochastic mathematical model developed in this study includes the most important class of biological growth relationships used in forestry, cost and price estimating routines based on functional relationships to cost and price influencing factors, procedures for generating losses from fires, storms, insects, and disease, and procedures for summarizing the record of each trial to financial measures of financial returns.

Construction of such a simulation model requires a number of methodological innovations. The model has to incorporate several modes of projecting stand growth based on diverse biological research, provide a flexible system of simulating sequences of timber treatments. In addition the approach requires means to estimate the variance of cost and revenue estimates, and probability distributions for losses

from fire, storm, insects and disease.

The results of this study may be applied in two ways: first, to help suggest a more complete explanation than is available for the currently observed pattern of management among types and sizes of ownerships, and second, and more important, to provide guides and rationale for decisions on intensification of management by individual owners and for policy formulation by public and private agencies administering programs in forestry and land management.[3/]

The remaining chapters of the study are:[4/]

2. Brief review of TRENDS IN SOUTHERN PINE FORESTS AND THEIR MANAGEMENT.

3. Development of an ECONOMIC MODEL OF TIMBER GROWING.

4. Description of a TIMBER GROWING FINANCIAL RETURNS SIMULATOR.

5. Selection of BIOLOGICAL MODELS OF GROWTH AND DEVELOPMENT OF SOUTHERN PINE TIMBER STANDS.

6. Analysis of PATTERNS AND TRENDS IN SOUTHERN PINE TIMBER PRICES.

7. Analysis of DETERMINANTS AND TRENDS OF TIMBER GROWING COSTS.

8. Estimation of RISKS OF LOSS FROM FIRE, STORM, INSECTS, AND DISEASE.

9. Assessment of IMPACTS OF FEDERAL INCOME TAXES ON TIMBER GROWING.

10. Initial DETERMINISTIC SIMULATION OF ALTERNATIVE MANAGEMENT REGIMES.

11. SELECTING AMONG ALTERNATIVE REGIMES ACCORDING TO INCOME AND RISK.

12. SUMMARY AND CONCLUSIONS.

3/ The first application of results is in the realm of positive economics, the second, in normative economics.

4/ Because of the diverse nature of the material covered, each chapter will discuss pertinent publications and sources of material.

Chapter 2

SOUTHERN PINE FORESTS AND THEIR MANAGEMENT

The majority of intensively managed forest in the South[1/] is composed of four major species of southern pine. Though the four species differ in growth rates and characteristics, their wood is sold interchangeably as raw material for the lumber, plywood, and pulp and paper industries. Indeed, southern pine is the most important species group in the U.S. timber economy, and within the group, loblolly pine is the most important single species.

This chapter will describe the forest types which include the southern pine, feasible management systems that can grow southern pine, and management levels prevalent among major ownership classes.

Forest land in the South

Forest Types

Forest types can be classified and described several ways. Among them are: (a) the climax type toward which ecological succession would progress if man's cultural activities and natural catastrophies such as fire, storm, and insects or disease epidemic did not interfere, (b) the type that existed before settlement, (c) the type that presently exists, or (d) the type that would exist under optimum economic land management.

1/ In this study the South includes the states of Virginia, North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Tennessee, Louisiana, Arkansas, and the forested portions of eastern Texas and Oklahoma. This regional grouping is used by the U.S. Forest Survey for forest statistics and timber supply studies.

For operational and descriptive reasons the classification used by the Forest Survey is the forest type that presently exists, even though the type on specific tracts may change over time.[2/]

The forest types of concern to this study are:

1. Loblolly-shortleaf pine type (49.4 million acres) prevails throughout the northern portion of the Coastal Plain and over most of the Piedmont. Loblolly pine[3/] is the dominant species on better sites. Shortleaf pine, more cold-hardy than loblolly, is prevalent at higher elevations in the northern Piedmont and in the Ouachita Mountains in Arkansas and Oklahoma. Loblolly pine is favored for management because it grows more rapidly and is less susceptible to little leaf disease than shortleaf pine. Loblolly-shortleaf pine type will be succeeded by hardwoods if they are in the understory when the pine is removed.

2. Longleaf-slash pine type (18.3) million acres stretches from southern South Carolina to Louisiana in the Coastal Plain. Historically, longleaf pine produces the best old-growth heart pine timber. Longleaf has not been favored in recent forest management because it is susceptible to brown spot disease, which severely retards juvenile growth. Slash pine, the other principal species, is favored for forest plantations within the type and areas immediately to the

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2/ More detailed descriptions of these forest types, or complexes of ecosystems of non-cultivated, non-urban land, are contained in Bjugstad et al. (1973). The most comprehensive treatment of the biological characteristics of reproduction, growth, and inter-species relationships is in Silvics of forest trees in the United States (USDA Forest Service, 1965).

3/ Scientific names of individual species are given in Appendix I. Loblolly pine, incidentally, derives its name from "loblolly" swamps along the Atlantic Coast, whose name in turn is derived from the seafaring term for the medicines aboard ship (Wahlenberg, 1960).

north where damage by ice storms and infection by fusiform rust is not severe. Mature longleaf-slash pine stands will also be invaded by hardwood understory if the pine overstory is cut.

3. Oak-pine type (30.9 million acres) includes stands in which four major southern pines comprise at least one-fourth but less than half the stocking. The rest may include a variety of upland oaks, hickories, gums, and other upland hardwood species. Often the pine is a remnant of more extensive pine stocking that has been removed. The hardwood component will generally take over if the pine is cut. Because pine timber is more valuable than upland hardwoods, management will normally favor pine in oak-pine forests, and remove the hardwoods to convert the stand to pure pine.

4. Oak-hickory type (56.3 million acres) is extremely diverse. It occurs in all but the bottomland geographic provinces of the South. It is characterized by various upland oaks, hickories, and other hardwood species, whose growth is slow to moderate. Except for fast growing yellow poplar, value of these species is low to moderate. Many oak-hickory stands are now being converted to pine plantations.

Four other southern forest types, oak-gum-cypress and elm-ash-cottonwood which grow in the Delta and other river bottomlands, and white-red-jack pine and beech-birch-maple types in the Appalachians, do not contain southern pines and cannot be coverted to them.[4/]

In addition to the forest types listed, some 5.0 million acres of nonstocked cutover land exist in the South. Such land is included

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4/ Excellent maps of all southern forest types are contained in A Forest atlas of the South (USDA Forest Service, Southern and Southeastern Forest Experiment Stations, 1969).

in commercial forest areas if it is evident that the land once was commercial forest and has not been converted to nonforest use, such as agricultural crops or improved pasture. Much of this land will revert naturally to forest within several years if seed sources are nearby. Planting such land will insure that the forest is well stocked and productive. In addition there have been extensive areas of idle agriculture land in the South. Each year more land is abandoned, but a portion of the idle areas reverts to forest naturally. In 1969, about 12 million acres were idle according to estimates made from the Census of Agriculture (USDC Bureau of Census, 1971).

Productivity of forest land

Land of all forest types in the South varies widely in inherent productivity. Productivity for timber growing differs from agricultural productivity because physiological needs of trees for water and nutrients are not the same as for field crops.

Two general means of rating forest productivity are in common use. First, the Forest Survey measures productivity of forest land in terms of potential growth of merchantable wood in cubic feet. This system, though perhaps not highly accurate, can be used universally and does not presume that land is best suited to the species now growing on it. The ratings are based on yields of extensively managed natural stands assuming fairly long rotations. Intensively managed stands and plantations on the same land may produce yields substantially in excess of the productivity class ratings. Below the productivity of 20 cubic feet a year, land is regarded as noncommercial forest.

Second, professional foresters often measure productivity by projecting height growth of dominant trees to an index age using height growth curves. In the South, usual index age is 50 years for natural stands and 25 years for plantations.

The following are rough equivalents in comparing Forest Survey productivity classes and site index classes.

Productivity class (cubic feet per acre per year)	Site Index (feet at 50 years)
120 or more	95 or more
85+ to 120	80+ to 95
50+ to 85	60+ to 80
20+ to 50	50+ to 60

The Forest Survey makes no claim that its implied break-even point for commercial timber growing is 20 cubic feet a year. Indeed, the results of this study suggest that land of site index 70 is barely marginal.

Table 2.1 shows the distribution of forest land by forest types and by productivity classes. The average productivity of the forest types does not differ greatly. It is highest for the bottomland types--oak-gum, cypress and elm-ash-cottonwood--and lowest for oak hickory. Loblolly-shoftleaf type has above average proportions of good sites.

Development of present use and ownership

Contrary to popular notion, settlement of the South was highly selective, converting only bottomland and Piedmont lands to agriculture. Most of the Coastal Plain piney woods were infertile and were left relatively undisturbed.

Table 2.1--Distribution of forest area in the South by forest types and by productivity classes, 1970

Forest types	20-50	50-85	85-220	120+	Total	Average 1/ Productivity
			Million acres			Cubic feet
Longleaf-slash	3.1	8.9	5.5	.8	18.3	76
Loblolly-shortleaf	5.2	23.0	16.3	4.9	49.4	83
Oak-pine	4.7	15.4	8.2	2.6	30.9	78
Oak-hickory	16.7	28.4	9.3	1.9	56.3	67
Oak-gum-cypress	3.2	10.9	12.8	2.4	29.3	85
Elm-ash-cottonwood	.2	.9	1.0	.7	2.8	95
Other forest types	.1	.4	.1	.1	.7	79
Nonstocked	2.8	1.7	.3	-	4.8	53
Total	36.0	89.6	53.5	13.	192.5	77

1/ Assuming the means of each class are: 20-50, 37 cubic feet per year 50-85; 50-85, 70 cubic feet; 85-120, 100 cubic feet; 120+, 135 cubic feet.

Lumbering was a local industry until the 1870's and 1880's. But from 1900 to 1925 the South was the leading source of U.S. timber. By 1930 the Coastal Plain piney woods and upland pine forests that covered most of the South in the 1800's were largely logged over. Then most large sawmills shut down or moved West to find virgin stands of timber. Remaining mills survived on remnants, limited second growth pine that seeded in on abandoned fields, and still uncut bottomland hardwoods. Frequent fires on vast areas of cutover land prevented regeneration.

Since the 1930's, fire protection, improved cutting practices, and forest management on industrial and public forests have restocked millions of acres of cutover land, increased growth, and substantially rebuilt the resource (USDA Forest Service, 1965). Southern forests now furnish at least 40 percent of the U.S. timber supply.

In the 1940's, 1950's, and early 1960's, reversion of other land to forest more than offset shifts of land out of forest. Between 1953 and 1963, commercial forest area in the South increased 4.0 percent. From 1963 to 1970, the area decreased 2.9 percent, as losses of forest land to reservoirs, soybeans and other crops, highways, recreation, industrial, and urban purposes exceeded reversion of agricultural land. Land shifts have tended to decrease forest area west of the Mississippi River and in Florida, have been nearly offsetting in Mississippi, Alabama, and Georgia, and have increased forest area along the Atlantic Coast.

Individual owners continue to own most of the South's forest. Much of the South's area has been farmed at some time, or has been in

woodland attached to farms or plantations. This land has usually been bought and sold many times, and still is largely owned by farmers and other private owners in all walks of life. Such land comprises about three-fourths of the area of southern commercial forests (table 2.2).[5/] The land's output is shown in Table 2.3.

Area owned by individual owners has been nearly static since 1952. This ownership class is not likely to increase, even though agricultural land is still being abandoned in upland areas. In South Carolina, for example, roughly one-third of the land in crops in 1947 had been put to other uses by 1968. Though some 1.8 million acres of cropland were lost, the net gain of forest land was only .5 million acres. If crop land in the state were to drop another third in the next 20 years, forest would not likely increase more than .2 million acres, less than 2 percent of present forest area.

Though forest area held by other owners has been nearly static in the last 15 years, major shifts have occurred in the proportion owned by various types of persons. Since 1953, the share of the South's forest land owned by farmers has dropped from 48 percent to 34 percent as number of farms and crop area have decreased. As farmers moved to cities or took town jobs, their Forest Survey classification changed. Land owned by miscellaneous private owners rose from 27 percent to 39 percent. Because of classification problems it seems likely that the Forest Survey has underestimated the shift away from farm ownership.

5/ Such owners are called, very loosely, "individual owners" in this study even though they include some 7 million acres owned by oil, mining, railroad, steamship and other industrial companies.

Table 2.2--Commercial forest land areas in the South, by ownership, 1970, and change since 1952

	Area	Proportion of total	Average annual change	Share pine type	Average productivity
	(M acres)	(percent)	(Percent	(Percent)	(Cubic feet)
Individual 1/	139.9	72.8	- .1	47.0	76
Forest industry	35.3	18.3	+ .5	67.2	82
National Forest	10.8	5.6	+ .2	55.6	71
Other public	6.5	3.3	+ .1	49.4	733
Total	192.5	100.0	.0	51.2	77

1/ Technically-farmer and miscellaneous private owners.

Table 2.3--Average inventory, growth, and removals per acre in the South, by ownership, 1970 and 1952

Ownership	1970			1952		
	All species	Softwoods	Hardwoods	All species	Softwoods	Hardwoods
	Cubic feet per acre					
Individual						
Inventory	773.1	341.1	432.0	641.1	225.8	415.3
Growth	40.7	24.4	16.3	29.9	14.7	15.2
Removals	34.2	19.9	14.3	29.6	14.9	14.6
Forest Industry						
Inventory	939.5	583.5	356.0	820.0	494.4	325.6
Growth	53.1	39.8	13.3	44.6	33.5	11.1
Removals	39.5	28.7	10.8	37.2	25.5	11.7
National Forest						
Inventory	1,128.5	643.0	485.5	827.4	466.4	361.0
Growth	54.5	37.0	17.6	39.4	27.5	11.9
Removals	12.6	10.2	2.4	7.9	5.8	2.1
Other Public						
Inventory	920.6	482.0	438.6	620.1	324.2	295.9
Growth	45.3	27.8	17.5	30.8	19.2	11.6
Removals	23.9	14.2	9.7	24.5	14.9	9.6
Total						
Inventory	828.9	407.4	421.5	680.4	286.9	393.4
Growth	44.7	28.1	16.7	32.9	18.7	14.2
Removals	33.7	20.8	12.9	29.5	16.2	13.3

Forest industry has owned large blocks of forest land since lumbermen from the North began acquiring timberlands in the post-Civil War era. The lumbermen purchased unsettled upland pine stands west of the Mississippi and less fertile piney woods areas that lay between Coastal Plain river bottoms. Most pulp and paper industry holdings were formerly owned by large lumber companies absorbed by the pulp and paper industry after they cut out. Most forest industry firms are still acquiring land. Though some purchases merely transfer land from one forest industry firm to another, purchases from non-forest industry owners are common.

National Forests and other public ownerships were formed largely from land purchased from defunct or cutover lumber industry holdings during the Depression. Some land was purchased from individuals in mountainous areas and to block up holdings. A significant share of public land is on military reservations. Management has emphasized restocking the land and improving timber stands.

Technology of southern pine timber production

Two broad management systems for growing timber, or silviculture, are: (a) even-age management, in which all trees on a given area are harvested in one or two cuts and the stand regenerated or planted at one time, and (b) all-aged management which maintains trees of all ages on a single stand. In all-aged management, periodic harvests leave the growing stock well-distributed among age classes by cutting large trees when financial mature, and thinning smaller trees.

Even-age management is favored in nearly all forest types where

the owner's objectives are primarily returns from timber growing.[6/] Most valuable timber species are "intolerant." They do not regenerate or grow well in shade of other trees, especially of the same species. Consequently all-aged management tends to encourage more tolerant, generally less valuable species in succeeding time periods, and prevent replacement of high-valued species in the stand. Second, net growth of all aged forests, where they are technically feasible, is generally substantially less than growth under even-age management. Third, average investment in growing stock in an all-age management system is usually greater than in even-aged management. Despite some controversy (Reynolds, 1955), even-aged management is nearly universally employed for all southern forest types except bottomland hardwoods. All regional studies in the South and elsewhere have presumed even-aged management.

Timber growing treatments

Timber growing practices and treatments seek to manage natural change in forest vegetation so as to produce desired timber output. There are two types of natural change: (a) the predictable growth of trees and other vegetation by small increments, year-by-year, and (b) unpredictable catastrophic changes caused by fire, storm, disease, and insects. Management practices can influence both rate of growth and risks from catastrophic losses. The practices can be grouped as follows:

6/ In forests where consideration of non-timber outputs or where protection of watershed, scenic, or other environmental values predominate, other management systems may be more appropriate.

1. Regeneration of the forest stand by planting, direct seeding, or "natural" means. Natural regeneration relies on germination of seed already on the ground or seeding from neighboring trees, seed trees, or a shelter wood canopy left after harvest. Among regeneration practices are slash disposal, removing unwanted vegetation and exposing mineral soil by controlled fire, or shearing, chopping, disking by heavy equipment, and planting seedlings, sowing seed. All of these practices require cash investments.

Regeneration may involve the change of species from those of one forest type to another (generally called type conversion), or replacement of the natural strain of trees with trees of genetically improved characteristics.

2. Stocking control, or cutting to removing an excess of unwanted trees. Improving growing space and quality of the remaining stand may involve cash investments in precommercial thinning, cull tree removal, or pruning. Often, however, the excess stocking can be removed with the owner receiving revenue. Such partial harvests are thinnings or improvement cuts.

3. Reduction of risks from fire, storm, insects, or disease. Risk-reducing practices include prescribed fire to remove unwanted dead fuel, or cutting trees already infected or which have a high risk of attack by insects or disease. Because the latter may involve premature harvest of merchantable timber, it is often income producing. Values received, however, are not as great as for the same timber removed during a scheduled harvest. Related to these practices is salvage of timber already killed by fire, storm, insects, or disease.

4. Harvest of timber yields. Final harvests of the entire stand may be at one cutting, or in several, as in seed tree and shelter-wood methods of regeneration. As mentioned, commercial thinning removes timber of merchantable value, with the dual purpose of obtaining value of trees that would otherwise be lost to natural mortality, and improving growing conditions of remaining timber.

5. Site productivity improvement practices applicable to some lands are drainage to remove standing or excess water, "bedding" the soil by forming the top soil into mounds before planting, and fertilization to overcome nutrient deficiencies.

Levels of forest management

Levels of management of forest land in the South have great diversity. For this study, a classification of management levels proved convenient to describe timber management in the South. The regimes and sequences of treatments that appear most prevalent for each level of pine management are:

0. Preservation without timber harvest.[7/] Many owners, for one reason or another, have not harvested timber for long periods (or since they have owned the tract) even though the timber is merchantable. Such owners constitute a small but significant proportion of individual forest landholders in most ownership surveys conducted in the South. In addition, some areas of parks, military reservations, wildlife refuges, and historical monuments have no timber cutting.

7/ This level is designated "0" because without timber revenues there is no point simulating the management level in this study.

If timber harvest is prohibited by law or specific administrative decision, the area is not included in commercial forest area.

I. Timber harvest without silvicultural treatment. This extensive method of forest management is prevalent on individual ownerships throughout the South. It is very simple. Some time after the timber grows to merchantable size and quality, owners sell to buyers who cut the timber under one of a variety of agreements. Sometimes the buyer has the right to take any tree he feels it will pay to cut--in pulpwood harvesting they may be only 4 or 5 inches in diameter. Often buyer and seller agree to cut trees larger than a specified diameter limit. In any case, the effect is to remove the most valuable portion of the stand, and let saplings and cull trees grow.

Often sufficient mineral soil is exposed so that pine seed present or disseminated from a neighboring pine stand may germinate and reestablish pine. If pine returns, the growth usually allows another cut in 20 to 25 years. In other cases, growth of hardwood understory or uncut cull trees following release precludes reestablishment of a pine stand. The forest type changes to hardwood--generally oak-hickory. Harvests may become less frequent or cease because the timber is not as merchantable.

For the owner, this level of management is entirely passive. He merely receives a windfall from the sale of timber every time a tract is sold. He needs no cash investment other than taxes and no professional management.

II. Unthinned natural stands. Regeneration at this level of

management provides for clearcutting followed by minimal mechanical site preparation and burning of slash and hardwood understory to promote regeneration of pine.

In Coastal Plain pine forests, the stand is given a controlled burn every 2 to 5 years. The fire prevents establishment of hardwoods in the understory, reduces fire hazards from accumulation of duff and litter, and makes access and harvesting cheaper. If burned regularly, no other hardwood control measure is needed. If not burned, as in the Piedmont, hardwood control of understory is needed before regeneration.

III. Unthinned natural stands with intensive regeneration treatment. This level provides several steps to insure optimal regeneration of the stand. Site preparation and removal of hardwoods is thorough. If regeneration is insufficient at age 3, the site is reprepared. If regeneration is too abundant the stand is precommercially thinned by checkerboard disking or chopping with tractor. On formerly oak-hickory or oak-pine types, the stand is sprayed with herbicide.

The stand is not thinned but clearcut at a relatively early age to obtain high cubic foot yields of pulpwood sized trees.

IV. Thinned natural stands. The same intensive regeneration treatment is given as in the previous level. The difference is that the stand is thinned as soon as the surplus basal area stocking can provide an economical pulpwood cut. Stands are thinned at 5-year intervals when young and usually 10-year intervals when they reach sawtimber size. Growth is concentrated on a relatively few trees

selected for form and vigor. The objective is sawtimber stands to be clearcut at age 40 or later.

For either levels III or IV, stands often need special treatment if management commences when stands are already established. Treatment usually consists of removal of cull trees and thinning to reduce stocking to 70 or 80 square feet of basal area, preferably only desirable trees. If the volume and quality of the trees removed is sufficient to produce revenue, the treatment is an improvement cut. After one or two timber stand improvement treatments, the stand can usually be managed as if management started with regeneration.

V. Unthinned plantation management with a pine stand. At this level of management artificial regeneration replaces highly unpredictable natural regeneration. To assure successful plantation establishment, clearcut harvests are quite clean, followed by intensive site preparation to remove uncut cull trees, hardwood understory, and brush. This allows planting by machine where the terrain is not too steep and rocky.

Investment in timber growing increases substantially because the cost of site preparation and planting. Yields from plantations, however, substantially exceed those from even well-stocked natural stands. Or the same yields can be obtained with shorter rotations.

With good planting stock, it is rare when survival is so poor that the tract needs repreparation and replanting. Serious infection from fusiform rust is relatively common, however. In high fusiform hazard areas, additional trees are often planted and the stand is thinned at age 3 or 4 to eliminate badly infected trees and reduce

stocking to desired levels.

VI. Thinned plantations. This management level differs only in that the plantations are thinned. Thinning starts at the time excess basal area provides enough volume for a merchantable cut, usually at age 15 or sooner. As with natural stands, the objective is production of sawtimber.

There are definite dangers in thinning plantations. Thinned plantations are prone to attack from bark beetles and, more seriously, Fomes annosus root rot. Losses may be sufficiently serious to eliminate economic gains from thinning.

VII. Intensive plantation management. This is not a homogenous management type, but in this category are management regimes that include one or more practices not usually found as recently as 5 years ago. These are (a) use of planting stock from genetically superior sources, such as a grafted seed orchard, (b) fertilization of sapling or poletimber plantations within 5 to 10 years of harvest to add additional growth, (c) drainage of coastal or swampy pine land to increase the site quality. In general these practices are not widespread, except on forest industry ownerships. Gains from these practices are not now exactly known. Many forest industry firms believe them to be sufficiently rewarding to invest substantial sums in them.

The conventional wisdom

The forestry profession has evolved a set of management guides for growing southern pine. Many are based on the limited published results already cited (Fasick and Yoho, 1965; Anderson, 1968; Anderson

and Guttenberg, 1971) which usually employ published yield estimates, assumed average prices per cord and thousand board feet, and estimated costs. A large number of other unpublished studies have been made by state forestry organizations, and the State and Private Forestry Assistance Programs of the U.S. Forest Service. Most of these have determined measures of financial returns using the computer technique developed by the author (Row, 1963).

A large influence on this conventional wisdom is the teaching of forestry schools and the evolved standard practice of large forestry organizations, whether based on analysis or not.

This conventional wisdom can be summarized as follows:

1. On all land capable of growing southern pine, minimal management produces greater returns than no management. Minimal management includes site preparation of cutover land to expose seed beds and reduce hardwood competition to improve chances of regeneration, and prescribed burning to reduce fire hazard and invasion of hardwood in all stands.

2. On almost all land, planting produces greater financial returns than natural regeneration.

3. Whether thinned stands produce more income than unthinned stands depends on relative anticipated prices for pulpwood or sawtimber. Since internal prices of pulp and paper companies favor pulpwood to protect mill supplies, they tend not to thin stands. Lumber companies tend to thin since that increases the proportion of sawtimber in the yields. Advice varies for owners selling on the market, suggesting that likely returns from thinned and unthinned stands may be similar.

4. The best rotation age for unthinned stands, either natural or plantations, is about 30 years. For thinned stands, the best rotation age is about 40 years.

5. Thinning, if any, should start as soon as average tree diameter and volume in excess of the deserved reserved stand allows a substantial pulpwood cut. This "captures" mortality experienced in dense stands. Natural stands on average sites are ready to thin by age 20, and in plantations by age 15.

6. If the stand is thinned, basal area reserved after thinning should equal roughly the site index.

7. After one or two initial thinnings, and particularly after the stand reaches the size of small sawtimber, thinning should not be made more often than every 10 years. This is not so much based on expected returns as on reduction of exposure to insects and disease.

The simulations and economic evaluations of management levels to be made in Chapter 10 will permit this conventional wisdom to be tested. Comparisons of what the evaluations suggest to be the best management policy with prevalent levels of management for ownership classes are presented in Chapter 11.

Summary

This chapter has presented the background situation for this study of timber growing profitability--where southern pine grows, how it can be managed, and current management patterns. The feasible technology suggests that the potential productivity of the South as a timber producing region is much larger than present output rates

seem to indicate.

The most significant and limiting factor, is the low level of management of individual ownerships. This raises these questions: Is the level of management low because management of the scattered tracts is uneconomic? If institutional and owner awareness problems are overcome, what levels of output from these lands are justified by financial returns?

Chapter 3

AN ECONOMIC MODEL OF TIMBER GROWING

Before going further, a brief resume of economic production theory as it applies to timber growing is needed. The economic theory of timber growing differs from most other production processes in that: (a) production extends over long periods of time, often 100 years or more, (b) the product (trees) is also a major factor of future production, (c) timber growing is highly capital intensive, as the result of the accumulation of timber growing stock, and (d) large external economies and diseconomies affect management decisions of many owners (Duerr and Vaux, 1953, Gregory, 1971). Some aspects of the economics of timber growing have long been a text example in capital theory (Fisher, 1930, Lutz and Lutz, 1951; Boulding, 1960; Hirshleifer, 1971), in particular the period of time to hold an appreciating asset.

The general model of timber growing evaluation this chapter develops has several objectives:

1. To relate the economics of timber growing to that of general economics of the firm, and to the theory of capital in particular,

2. To discuss the feasible means of evaluating the model and explain why simulation was chosen as the only practical alternative for management regimes incorporating even the most essential elements,

3. To present the basic concept of the dual evaluation criteria for management levels--expected average returns and variance of returns,

4. To establish criteria for biological, price, and cost functions with which to quantify the model.

General framework

To aid in the presentation of the model, and in subsequent development of explicit functional relationships in later chapters, the following symbols will be used throughout:

General fixed or exogenous factors

A = Area of tract in acres

SI = Site index of tract

LC = Land class: 1 - cutover, 2 - old field, 3 - cull hardwood

OWN = Owner class: 1 - individual, 2 - corporate

i = Owner's guiding rate of return

RAT = Owner's marginal tax rate on ordinary income

RAG = Owner's marginal tax rate on capital gains

T = Time in years when used as a variable in function

E = Random number from 0 to 1

Subscripts used for stand attributes, costs, revenues, and results

j = Order of treatments specified

k = Order of harvests specified

p = Order of price or cost influencing factors

n = Number of periods in the management regime

m = Length of period in years

t = Order of years within management regime

$t0$ = Time of investment initation, or trial start

te = Age at which regeneration is completely established

tz = Rotation age, or age of final clearcut harvest

tj = Age of treatment $\underline{X}_j$

tk = Age of harvest $\underline{Y}_k$

Stand variables

B_t = Basal area per acre

D_t = Average tree diameter

N_t = Number of trees per acre

Y_t = Volume of timber per acre

S_t = Stocking index

Q_t = Quality index

Management decision parameters

X_j = One of set of $\underline{nj}$ treatments

XL_j = Intensity level $\underline{X}_j$ treatment

H_k = One of set of $\underline{nk}$ harvests (volume cut is $\underline{Y}^{**}_{tk}$)

BG = Basal area guide if thinnings are made

Revenue variables

P_k = Unit price for harvest $\underline{H}_k$

FP = Fixed revenue factor for any harvest

PV_p = One of set of $\underline{np}$ price influencing factors

R_k = Gross cash revenue per acre from harvest $\underline{H}_k$

TR_k = Gross cash revenue for tract for harvest $\underline{H}_k$

NR_k = Net after-tax revenue from tract for harvest $\underline{H}_k$

Cost variables

VC_j = Variable cost of treatment $\underline{X}_j$ per acre

FC_j = Fixed cost of treatment X_j

NT = Number of tracts in treatment

CV_{jp} = One of set of njp cost influencing factors for X_j

Financial return values

W_t = Value of investment at time t for one rotation

WP_t = Value of investment at time t for perpetual series of rotations

I = Equivalent annual income per acre from t0 onward

r = Rate-of-return on investment at t0

LV = Market land value per acre

EV = "Entreprenuerial" value per acre, or WP_{t0} - LV

The tract

The scale of this model is a tract of timber.[1/] Using the tract differs from the usual practice in evaluating single forestry management regimes, which normally make all projections in per acre terms.

There are several reasons for choosing the tract instead of some other unit for analysis:

1. A tract or similar sized unit is the smallest unit that can be managed as a single production entity. Timber sales and treatments are generally planned and conducted for at least one tract or a tract-sized unit. In timber sales and treatments there are strong economies

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1/Most relationships included in the model have scale effects--costs, prices, taxes, and losses from fire, storm, insects and disease. These are computed for the tract. Tract values are subsequently divided by acres to reduce the range of values needed in tabulations. There are no scale effects in the growth functions, though minor but clearly evident "border" effects are visible in actual stands.

of scale.

2. Large forest properties are generally subdivided into subunits or compartments of a size from 50 or so to several hundred acres. Rarely are properties over 1000 acres planned or operated without subdividing them according to tracts, stands, compartments, or other subdivisions. Thus tract-sized units are essential building blocks in evaluation of larger ownerships. All present systems of analysis of large ownerships by linear programming use activities for different timber types on a per acre basis (Navon, 1971, Clutter and Bampting, 1971), though the specification that units or compartments be considered indivisible units has only been used by Randall (1972) in integer programming formulations.

The tract or other unit has only two significant attibutes that are unchanged as a simulation progresses. These are the area of tract (A), the site index (SI), or measure of land productivity discussed in Chapter 2. The land class (LC), or condition at initial investment, may be changed at the end of a rotation, if a multi-rotation trial is being made.

The tract's owner

The evaluation of the financial returns of growing timber on the tract is from the viewpoint of the owner and manager of the tract. In this study it is assumed that the owner or manager plans and operates the tract as an independent investment. The problem of the optimal combination of timber growing regimes on a number of tracts or subcompartments is an extension of the problem

that will not be considered in this study. The type of intensive evaluations of individual regimes is a prerequisite, however, for analysis of large ownerships.

The owner has several fixed attributes that influence the evaluation of timber growing investments. These are the guiding rate-of-return (i), the owner's marginal tax rate on ordinary income (RAT), his marginal rate on capital gains (RAG), and whether he is taxed as an individual or a corporation.

The guiding rate-of-return, i, deserves special comment. If the owner has greater investment alternatives than his supply of available capital funds, i is the rate at which he can borrow. It is assumed that he can borrow sufficient capital to manage his tract of forest land at rate i. If the owner's available capital exceeds his alternatives to invest, i is the rate at which he can loan funds or invest in nonforest activities. Thus for the owner the supply of the capital factor of production is perfectly elastic. His capital fund is not a "closed system." These assumptions follow those of Hirshleifer (1958), in his On the theory of optimal investment decisions.

The owner contracts all necessary practices in timber growing that involve employment of labor. The amount of work that he can contract at estimated prices exceeds that required for management of the timber tract. Supplies of other factors of production are also perfectly elastic.

With amount of land fixed, and supplies of capital and contracted labor elastic, the owner seeks to come as close as feasible to

the optimal value of the stream of cash flows from revenues and costs of managing his tract. By optimal he has at least two criteria:

1. The average or expected value of the income stream (I), and

2. The risk and uncertainty that returns will sharply differ from this expected value. In general it will be assumed that the owner would require that increased risk and uncertainty be offset by increased expected income.

Time periods

The owner creates the stream of income by performing treatments that lead to timber production on his tract. The production occurs over n time periods, each of which is m years long. Thus at the end of each period, the time in investment years (t) is a multiple of m: t = 1*m, 2*m,... n*m. The output of the production process is considered available for sale at the end of a time period. Several points in time, or specific t investment years, are important. They are:

t0 = The beginning of period 1, at which time many of the investment treatments are made.

te = Age at which no more regeneration will occur, and the stand is considered established. The stand at this time can be measured and projected forward. In this study it is at te = 0.

tz = Age at which the stand is planned to be clearcut and regenerated with a new stand.

If the owner's time horizon is just one rotation n*m = tz. But the

owner's time horizon may take in an integral number of these tz rotation periods, or a perpetual series of them.

When time is used as an argument or variable in a functional relationship, it is expressed as T. In growth functions where T is frequently used, the time variable is stand age, which may be slightly less than investment age because of a lag in regeneration.

Management decision parameters

In order to secure this optimum stream of income from his investment, the owner must make a number of management decisions or decide on several management parameters. The major goal of this model (and this study) is to determine the optimal set of management parameters for a given set of attributes of the tract and its owner. These are:

X_j = A set of nj treatments, with j =], 2,... nj. The set of treatments chosen, X, is a subset of all possible treatments defined by treatment type and treatment intensity. Each of these X_j treatments occurs at a specific time symbolized by tj.

Y^{**}_k = A set of nk harvests, with k = 1, 2, ... nk. The set of harvests chosen, Y, is similarly a subset of all possible harvests defined by intensity and timing. Each of these harvests occurs at a specific time designated by tk. A specially significant harvest is the final clearcut harvest at the end of the rotation, which is symbolized by Y^{**}_{tz}.

BG = Basal area guide to which the stand is thinned, if thinnings are made. In this study a constant basal area guide is used.

For convenience in the analysis, sets of treatments are grouped into management levels according to the prevalent management practices in growing southern pine timber. Seven such sets were described in Chapter 2.

Stand attributes

From the time the stand is completely established, te, to the time it is cut, tz, the stand can be described in terms of seven attributes. These are:

B_t = Basal area $(.005454 * D_t^2 * N_t)$

D_t = Average tree diameter $[(B_t * .005454 * N_t)^{.5}]$

N_t = Number of trees over 1 inch D $[B_t / (.005454 * D_t^2)]$

Y_t = Volume of stand in cubic feet per acre

S_t = Stocking expressed as an index, with "normal" stocking equated to 100

H_t = Average height of dominant and codominant trees

Q_t = Quality of stand in terms of an index from 0 to 100 representing approximately the percent A and B grades of trees.

As indicated in the first three definitions, the attributes B_t, D_t, and N_t have a fixed relation to each other at all times. In addition a fourth of these attributes, Y_t, is determined by a combination of the others:[2/]

$$Y_t = f(H_t, D_t, N_t) \quad \text{or} \quad Y_t = f^{\circ}(H_t, B_t)$$

2/Implicit functions will be used throughout this chapter. In Chapters 5 through 9, the explicit functions will be developed.

This fixed volume function is regarded in this study as fixed and without error. The equations appropriate to different types of stands are discussed in Chapter 5. Similarly stocking, S_t, is a fixed function of age, basal area, and number of trees:

$$S_t = f(T, B_t, N_t)$$

Modifications of these variables denoting portions of the stand in thinnings are:

B_t^*, D_t^*, N_t^*, H_t^*, and Y_t^* = Attributes of the portion left, and

B_t^{**}, D_t^{**}, N_t^{**}, H_t^{**}, and Y_t^{**} = Attributes of the portion cut.

Timber growth and development model

This section will outline the physical-biological functions that determine the output of timber products in physical units and quality characteristics. This will include the response of the output to various types of treatments. The initial presentation will be in terms of the classical yield concepts of forestry, and subsequently the presentation will develop the more elaborate aggregate stand estimation concepts used in this study. The approach is derived largely from Schumacher and Coile (1960).

The classical yield model

The simplest, and still frequently used model of timber growth is a function of only stand age:

$$Y_t = f(T)$$

in which the explicit form is a polynomial, logarithmic, or logistic function. Often separate functions are derived for different types,

locations, or productivity classes. It is common, however, to recognize the influence of productivity directly into the function, in this case the variable SI. With such a form the model is completely deterministic and gives but one yield estimate for a stand of given age and productivity class. In practice, immature stands with greater or less volume than predicted for their age are encountered, and estimates of final yield are desired. Thus a measure of stocking is introduced, which in most cases is Y_{te} at the age the stand is considered established. In effect, the yield equation becomes:

$$Y_t = f(T, SI, Y_{te})$$

Usually a given equation is applicable to only one land class, LC.

On a per acre basis, growth is a steady cumulative process that can be described mathematically by a derivative of (3.2), or a difference equation that estimates the volume at the end of the period from the volume at the start:

$$GY_t = dY/dT = f'(T, SI, Y_t) \qquad (3.5)$$

Most studies of physical yields of timber have developed equations for forest growth in the form of these equations (Davis, 1966; Schumacher and Coile, 1960; Clutter, 1963). The principal elaboration is the separation of growing stock into components based on species, diameter, and height distribution.3/

Often the function employs a concept called "return to normality"

3/The difference form of growth equations is actually more realistic because (a) timber growth is concentrated in only several months of the year, (b) management decisions are made at periodic intervals, and (c) is operationally more useful in computer programming applications in complex situations. The continuous form is used by Bierman (1968) and Clutter (1963), and is easier to present.

in which it is assumed that a stand that does not have normal stocking tends to grow at rates that will cause the yields to converge with normal yields over time. The concept, which is used in a slightly modified form in Schumacher and Coile (1960) and in this study, is explained in greater detail in Chapter 5.

The major difficulties that limit the usefulness of this direct yield estimation approach in financial analysis are: (a) Yields or outputs are specified in physical units of only one type. Only one yield study has developed product yields in both sawtimber and pulpwood (Bennett and Clutter, 1968, (b) Responses to treatments are difficult to model with just one stand descriptor. Similarly the impacts of fire, storm, insects, and disease are difficult to incorporate.

The criteria for models to project the physical-biological yields are discussed in detail in Chapter 5. The alternate concepts by which the models can be developed are assessed against these criteria.

A multiple attribute stand model

The model employed in this study attempts to overcome these difficulties by disaggregating the growth process into components both in terms of time and in terms of growth functions that affect stand components in different ways. Most of the ideas are not original, though the synthesis of the components into a dynamic stand model which can be incorporated into a simulation program is unique.

Though it is possible to develop a growth function for the first few years after regeneration, it is more practical to estimate initial volume at an age te at which the volume is readily measurable. This occurs before the stand is likely to be commercially cut for any product. Thus one of the initial tasks is to estimate the stand at establishment time, te. There are three attributes that must be separately estimated by functions based upon tract attributes and regeneration treatments. These functions are:

$$H_t = f(T, SI)$$

which is a height growth function applicable any time during the development of the stand, and

$$N_{te} = f(SI, LC, X_1, X_2, \ldots X_j, \ldots X_{nj}) \qquad (3.6)$$

$$B_{te} = f(SI, LC, X_1, X_2, \ldots X_j, \ldots X_{nj}) \qquad (3.7)$$

From these functions can be derived the basal area by its definition, and the volume (V_{te}), if any, from equation (3.1). The quality index is 0 at te.

From this first estimate of stand establishment, the projection of stand development continues. The approach to projection employs functions to estimate changes in the same three attributes as was estimated for regenerated stands--height, basal area, and numbers of trees. The function for height (3.6) is used to estimate the height of the stand at the end of the growth period. Basal area growth is estimated using a form of equation (3.5) for natural stands, either unthinned or thinned. If the time at the beginning of a projection period is ta and at the end tb, the equation for

projected basal area has the form:

$$B_{tb} = B_{ta} + \int_{te}^{tb} f'(T, SI, B_t) \qquad (3.9)$$

Changes in the number of trees is estimated from a mortality function of the following form:

$$N_{tb} = N_{ta} - \int_{te}^{tb} f(T, SI, B_t) \qquad (3.10)$$

From estimates of $\underline{B}_t$, $\underline{N}_t$, and $\underline{H}_t$, the diameter, $\underline{B}_t$, is obtained by definition, and the volume, $\underline{V}_t$, is obtained by equation (3.1). Stand quality, $\underline{Q}_t$, is a function of age and stocking:

$$Q_{tb} = Q_{ta} + \int_{ta}^{tb} f(S_t) \qquad (3.11)$$

An exception to these procedures is the estimation of yields of unthinned loblolly pine plantations. A procedure for estimating directly the number and diameter of surviving trees directly from the age, site index, and original number of seedlings planted is available from Lenhart and Clutter (1971).

If the stand is thinned, the specifications include the age of thinning and the guide level for the remaining basal area ($\underline{BG}$), which is a management parameter. The diameter of trees left, $\underline{D}_{tk}$, after thinning or harvest $\underline{k}$ can be estimated from a function of the form:

$$D^*_{tk} = f(D_{tk}, B_{tk}, BG, T) \qquad (3.12)$$

The number of trees left is obtained from the definitional relationship of basal area, diameter, and number of trees. The volume remaining is estimated from equation (3.1). The volume, diameter, number of trees, and height of the trees cut is computed from the differences between original and remaining basal area,

number of trees, and volume of stand. Forward projections are obtained from substituting $\underline{B}^{*}_{tk}$ and $\underline{N}^{*}_{tk}$ into equations (3.9) and (3.10). The output of thinning treatments is expressed as $\underline{Y}^{**}_{tk}=\underline{Y}_{tk}-Y^{*}_{tk}$. It has associated with it the attributes of diameter ($\underline{D}^{**}_{tk}$) and height ($\underline{H}^{**}_{tk}$).

At the end of the rotation the final harvest removes all of the remaining volume, $\underline{Y}_{tz}$, and with this is associated the stand attributes of diameter, height, and grade of the entire stand.

Variability of yields

Variability of growth processes is recognized by the estimation of the standard error of certain of the foregoing functions. The modifications of the functions are:

$$H_t = f(T, SI) + e[E(\sigma_h)] \qquad (3.6a)$$

$$N_{te} = f(SI, LC, X_1, X_2, \ldots X_j, \ldots X_{nj}, E) \qquad (3.7a)$$

$$B_{te} = f(SI, LC, X_1, X_2, \ldots X_j, \ldots X_{nj}, E) \qquad (3.7a)$$

$$B_{tb} = B_{ta} + \int_{ta}^{tb} f(T, SI, B_t) + e[E(\sigma_g)] \qquad (3.9a)$$

in which $e[E(\sigma_h)]$ and $e[E(\sigma_g)]$ indicate simulated errors based on a uniform random probability $\underline{E}$ which ranges from 0 to 1. For the number of trees and basal area after the regeneration period, the random probability is directly incorporated into the estimation procedure. The functions are described in detail in Chapter 5.

Other causes of variability in yields are fire, storms, insects, and disease, which will be discussed in Chapter 9. For analytical purposes they can be handled in the same manner as growth variation.

Diagrammatic illustrations of the processes in stand development are shown in figures 3.1 and 3.2. The data are those developed in Chapter 10 for site 80 under intensive management of natural stands.

Figure 3.1 shows the sigmoid curve of total height growth, and a similar trend in diameter growth. If the stand is thinned, the removal of smaller trees automatically increases average stand diameter (dotted lines). Also shown is the decline in number of trees from mortality. Most of the mortality is caused by tree competition, with the less aggressive trees gradually disappearing. Thinning sharply reduces mortality.

Figure 3.2 shows the trend of stocking in terms of basal area and cubic volume. Growth of both slow notably if the stand if not thinned. The thinning reduces the basal area to a level specified by the owner (here 80 square feet). Because the trees continually grow in height, the volume which remains increases with each thinning.

Figure 3.1--The development of a natural timber stand in terms of total height, overage diameter, and number of trees. Illustrative data are those of an average stand on site 80 under management levels III--unthinned high intensive site preparation (solid lines) and level IV--thinned.

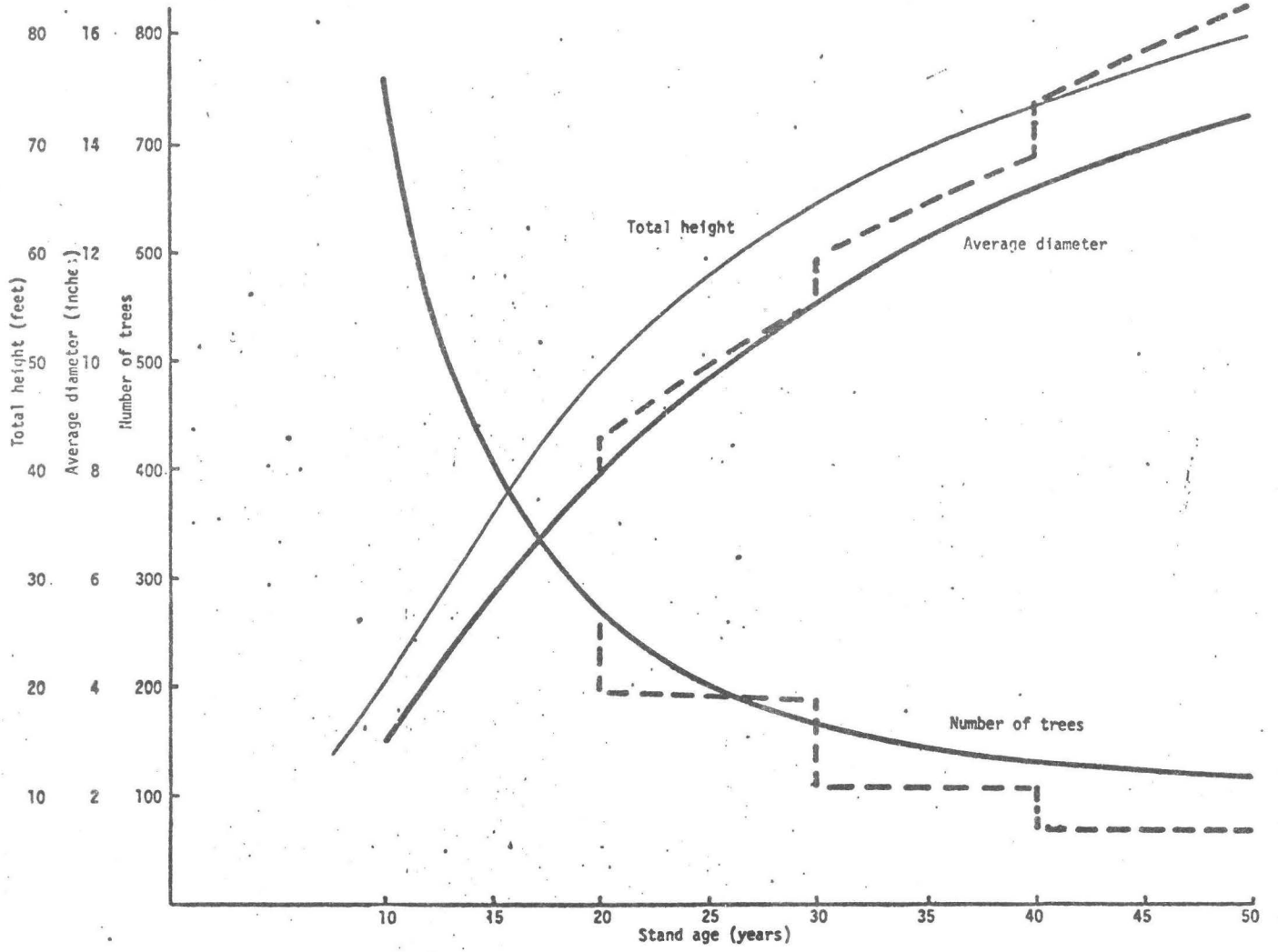
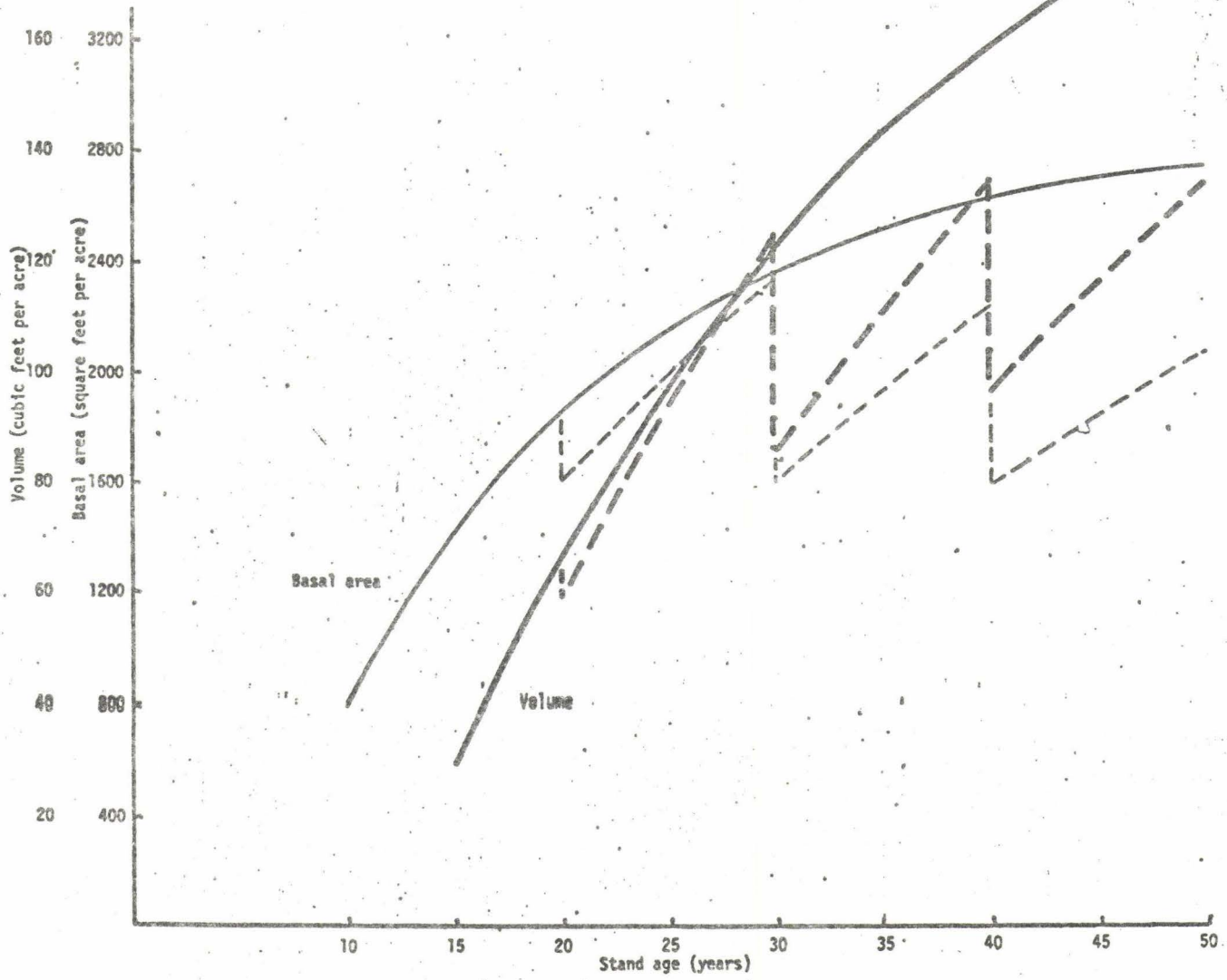


Figure 3.2--Development of stand stocking in terms of total volume (heavy lines) Same stand as in figure 3.1.



Economic evaluation model

The management parameters and the physical-biological growth model generate a series of treatment or inputs ($\underline{X}_j$) and outputs ($\underline{Y}^{**}_k$). Since both of these series are in physical terms, the first tasks of financial analysis are to put these in terms of net cost and revenue.

Revenues

The revenue from sale of the timber harvested, either $\underline{Y}^{**}_{tz}$ at final harvest or $\underline{Y}^{**}_{tk}$ for thinnings, must be estimated by a functional relationship that includes the major influencing factors. In this section, all timber cuts will be handled the same way. Previous analyses have tended simply to multiply the amount sold by fixed unit prices, either for the total yield or for several components, on a per acre basis. In symbols this would be:

$$R_k = P * Y^{**}_{tk} \tag{3.13}$$

P is not subscripted since it is in this case fixed.

Instead, the model in this study expands this relationship by expressing revenue on a tract basis by multiplying by acres. This permits the addition of a fixed price constant ($\underline{FP}$). The constant is likely to be negative since it represents the fixed costs of purchasing the timber and moving the logging equipment to and from the tract. The equation for the expanded total revenue is:

$$TR_k = FP + P * Y^{**}_{tk} * A \tag{3.14}$$

Furthermore both the fixed price and the per unit price are functions of influencing factors. For example, the fixed price per tract (that is, the portion of total revenue which does not

depend on the amount sold) is primarily a function of acreage in the tract, or

$$FP = f(A) \tag{3.15}$$

The price per unit of timber sold, however, is influenced by such factors as diameter, height, average volume per tree, and grade. If we assume some np variables, PV_1, PV_2,... PV_p,... PV_{np}, then the implicit equation for the unit prices is:

$$P_k = f(PV_1, PV_2, \ldots PV_p, \ldots PV_{np}) \tag{3.16}$$

The total revenue function for the tract then becomes:

$$TR_k = f(A) + Y^{**}_{tk} * f(PV_1, PV_2, \ldots PV_p, \ldots PV_{np}) + e[(\sigma_r)] \tag{3.17}$$

where $e[E(\sigma_r)]$ is the simulated error which is a function of a random probability and the standard error associated with that total revenue.

Net revenue is the amount that is left after the net tax rate is applied to the gross revenue. This can be expressed as:

$$NR_k = TR_k * (1. - f(OWN, RAT, RAG)) \tag{3.18}$$

with the function for revenue tax dependent on the type of ownership, and the tax rates on ordinary income and capital gains. This tax situation for timber revenues is described in Chapter 9.

Treatment costs

In a similar fashion, the model developed in this study includes treatment costs as functions of a number of both specified exogenous and endogenous variables. Unlike prices, however, there are a number of treatments whose costs per acre can be expressed as C_j with $j = 1, 2, \ldots nj$. As with the prices a total tract cost is composed

of a fixed cost and a per unit cost, which in this case is an acre. The general equation for each treatment is:

$$TC_j = FC_j + CV_j * A$$

The fixed costs appear to comprise a basic fixed cost and a cost for each separate tract:

$$FC_j = f(NT)$$

Like the unit prices for timber, the variable costs per acre for each treatment is a function of the treatment intensity, $\underline{XL}_j$, associated with each $\underline{X}_j$, and a number of variables, $\underline{CV}_{jp}$, with $1 = 1, 2, \ldots njp$. The implicit equation for each treatment then is as follows:

$$TC_j = f(NT) + A * f(XL_j, CV_{j1}, CV_{j1}, \ldots CV_{jp}, \ldots CV_{njp}) \; e[E(\sigma_c)] \qquad (3.20)$$

where $e[E(\sigma_c)]$ is the simulated error associated with the estimated cost.

Note that here is a separate equation with a unique set of explanatory variables for each treatment.

There is also a special class of costs that occur annually at a constant rate not dependent on endogenous variables in the simulation model. Collectively these fixed costs are designated as $\underline{MC}$, or management costs.

For all of these costs the net aftertax cash cost is used in the financial evaluation. This can be expressed in a similar fashion as the aftertax revenues:

$$NC_j = TC_j * (1. - f(OWN, RAT, RAG)) \qquad (3.21)$$

Figures 3.3 and 3.4 show the models of revenues and costs in diagrammatic terms. Both total tract values and per unit values are drawn, showing the effect of the fixed revenue factor and fixed costs in decreasing revenue and increasing costs for small tracts. The implications of the costs on income per year are developed in Chapter 10.

Figure 3.3--Diagram of the model for the revenue from timber harvests.

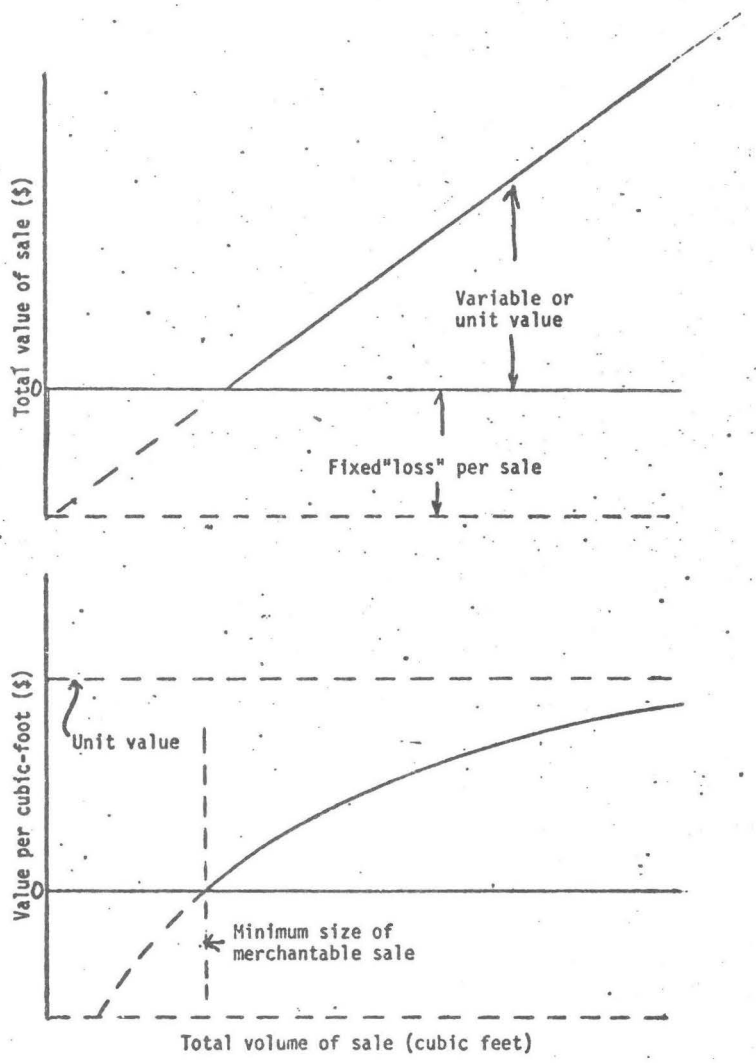
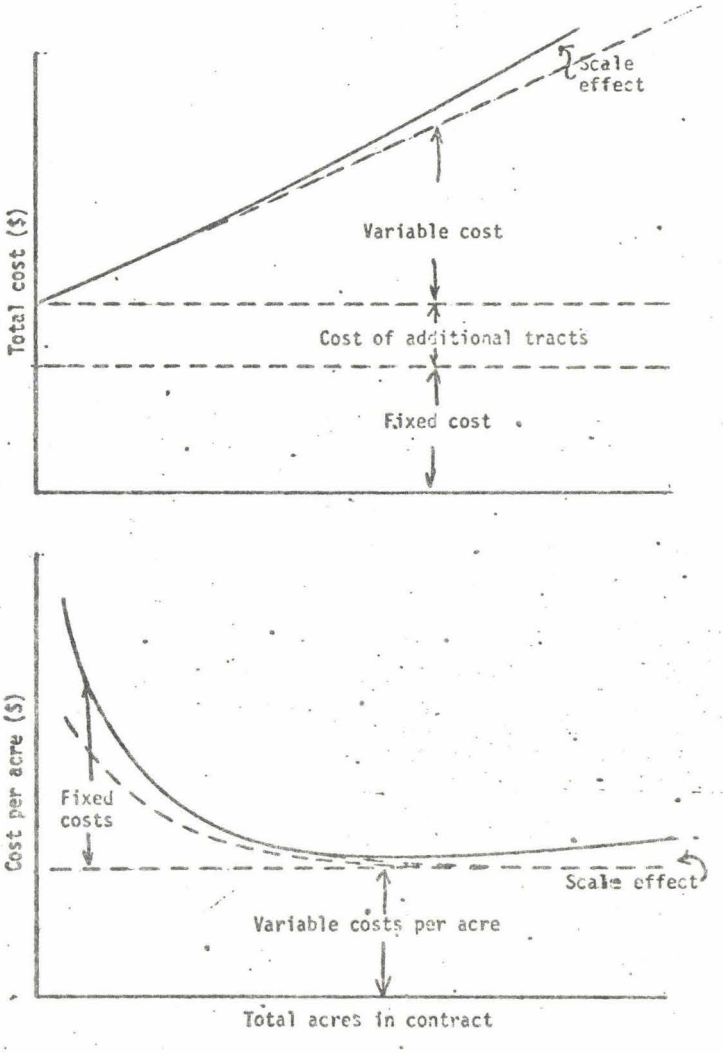


Figure 3.4--Diagram of the model for the costs of treatments.



The model summary

If the production period for growing timber were collapsed so that no distinction for time were made, the total income from a timber growing rotation of TZ years on a tract of A acres would be:

$$W_0 = NR_{tz} + \sum_{k=1}^{nk} NR_k - \sum_{j=1}^{nj} NC_j - MC * TZ * A \qquad (3.22)$$

There are two general ways to reduce the stream of revenue and cost cash flows to a single evaluation criterion. The first method assumes that owners of capital funds invested in a production process expect funds to earn a return--their guiding rate, and expect that periodic returns will be reinvested if they leave them in the process to accumulate. Thus the value of future benefits is only the amount that, if invested at their guiding rate, would grow at a compound rate to that future value. The familiar form for equating value from a future time period to the present value (W_{t0}) is:

$$W_{to} = W_t * (1 + i)^{-t}$$

Incorporating this discounting principle into the toal net revenue euqation (3.22) produces:

$$W_{t0} = NR_{tz} * (1 + i)^{-tz} + \sum_{j=1}^{nk} NR_k * (1 + i)^{-tk}$$

$$\sum_{j=1}^{nj} NC_j * (1 + i)^{-tj} - MC * [(1 + i)^{-tz} - 1] \qquad (3.24)$$

The optimization of the present net worth for a single sequence of regeneration and harvest, however, neglects the potential use of the land for another crop of timber. Such future crops also have present value. If it is assumed that future reforestation and harvest sequences

(or rotations in forestry) are identical to the first, the present net worth of the perpetual series is:

$$WP_{t0} = W_{t0} + W_{t0} * (1 + i)^{-tz} + W_{t0} * (1 + i)^{-tz*2} \ldots \quad (3.25)$$

Summing this infinite series:

$$WP_{t0} = W_{t0} * [1 + 1 / ((1 + i)^{-tz} - 1)] \quad (3.26)$$

If the second rotation is the first of a series that differs from the initial rotation, its discounted value may be designated $\underline{W^*_{to}}$. The present value of such a perpetual series is:

$$WP_{t0} = W_{t0} + W^*_{t0} * [1 / ((1 + i)^{-tz} - 1)] \quad (3.27)$$

And if the evaluation concerns a series of rotations that vary stochastically, the procedure used in this study is to simulate $\underline{n}$ consecutive rotations that total 80 years or longer, compute the present net value of the entire series, and convert to perpetual value by equation (3.26), but replacing $\underline{tz}$ with $\underline{n*tz}$.

A slight variation of the present value criterion is the equivalent annual income per acre ($\underline{I}$). The relationship between the present value and equivalent annual income is:

$$I = W * i \quad (3.28)$$

Though the present net value form is prevalent in forestry literature, equivalent annual income has many advantages for ease of presentation, incorporation of incomes from other multiple uses, and comparison with alternative land use. In addition, the scale of values produced is more easily comprehended and used by forest land managers. Use of the equivalent annual income form of present value will be standard in this study.

The other value criterion is the rate-of-return on investment. This is the value of i in equation (3.24) that exactly reduces the present value W_{t0} to zero. This rate-of-return is denoted by r. The rate-of-return concept has had a times past substantial vogue in the literature of investment analysis, in general as well as in forestry (Boulding, 1948). But the rate-of-return criterion will produce an incorrect ranking or selection of investments if (a) the capital system within the economic unit being analyzed is not closed (borrowing and lending is possible), (b) the investments are exclusive or interrelated. These conditions are present in this study, and the weight of opinion and analysis in the literature indicates a preference for present value under these conditions.

The conclusion that such an owner-investor would seek to optimize his present worth or equivalent annual income is demonstrated by Hirshleifer (1958, 1970), Hillier (1970), and Bierman (1968) in reference to general production processes and investment, and by Gaffney (1960), Beasley (1960), and Bentley and Teeguarden (1965) in analyses particularly pertaining to forest production. The references cited all discuss the distinctions between these criteria in detail. It has been claimed (Webster, 1962) that for most analyses of timber growing opportunities the two criteria indicate similar decisions. However, in forestry as in other fields, application of rate-of-return criteria encounters several problems, including that of multiple solutions or roots due to irregular streams of cash flows (Lorie and Savage, 1959; Gansner and Larson, 1969).

Considering land values

The market value of land (L) in a static economy in general equilibrium would be set by the highest present value of the land use alternative (forest or nonforest) of the owner with the lowest guiding rate of return i. Individual differences in borrowing and investment opportunities will maintain differences in i.

Owners with low i would be able to bid the highest for the land, and would come to acquire such land as they accumulate the capital or borrow to do so. Prices of outputs and costs would be stable. The system would operate to obtain optimum allocation of land to forest production. For forest owners, L would tend to equal W. L would be then based on pure rent.

But the economy, and particularly the forest production sector of it, is generally in various degrees of disequilibrium. Prices of land are frequently above or below an owner's capitalized value for it.

The present net worth, W, in equation (3.24) for a single rotation, or for a perpetual series in equation (3.26) may be greater or less than the land value, LV. If the difference, EV, is not positive, the owner would want to sell the land. An alternate way of presenting the problem is to consider the value of the land in the cost base and assuming the value of the land would remain after the harvest. In this case the present worth would be:

$$W_{t0} = LV + EV = (W_{tz} + LV) * (1 + i)^{-tz} \qquad (3.28)$$

or the net present value in excess of land values to the entrepreneur is:

$$EV = W * (1 + i)^{-tz} - LV * [1 - (1 + i)^{-tz}] \qquad (3.29)$$

This formulation treats both the original cost of growing stock and land as inputs to the production process. It is a slightly rearranged form of what Bentley and Teeguarden (1965) call the general financial maturity model.

A practical problem with using this formulation is that forest owners rarely have a firm idea of what the land value is. Even in the South, there is not a given market, nor even widely reported prices, for timber land. What land sells for depends on a wide range of circumstances which individual owners are in a poor position to gauge. Therefore the most convenient analytical form is equation (3.24).

Evaluation of risk and uncertainty. The distribution of returns from a given set of exogenous and management parameters may depart widely from a normal distribution. Some of these will be shown in Chapter 10. Nevertheless, the measure of risk or uncertainty[4/] to be used will be the standard error of the equivalent annual income per acre. Once both measures of the returns selected management regimes are obtained, they can be compared in a procedure analogous to portfolio analysis or Markowitz theory (Markowitz, 1959, Borch, 1967, Sharpe, 1970).

4/The terms risk and uncertainty are frequently given more restricted meanings. Risk often refers to situations in which the probability distributions are objectively derived, as in this study, and uncertainty where they are not. Here the term uncertainty will be used to cover all measures of uncertain outcomes.

For any particular timber growing situation or opportunity defined by tract area, site index, and condition class, the feasible regimes will be arrayed by both expected return and the standard deviation of return. This is illustrated in figure 3.1 in which the vertical axis is the expected return E, and the horizontal is the standard error σ or measure of the sum of the analyzed risks and estimated uncertainties.

It will be assumed that the owners will follow these rules for decisions:

1. Between two alternatives with the same uncertainty, the one with the greater equivalent income will be preferred.

2. Between two alternatives with the same equivalent income, the one with the smaller degree of uncertainty will be chosen.

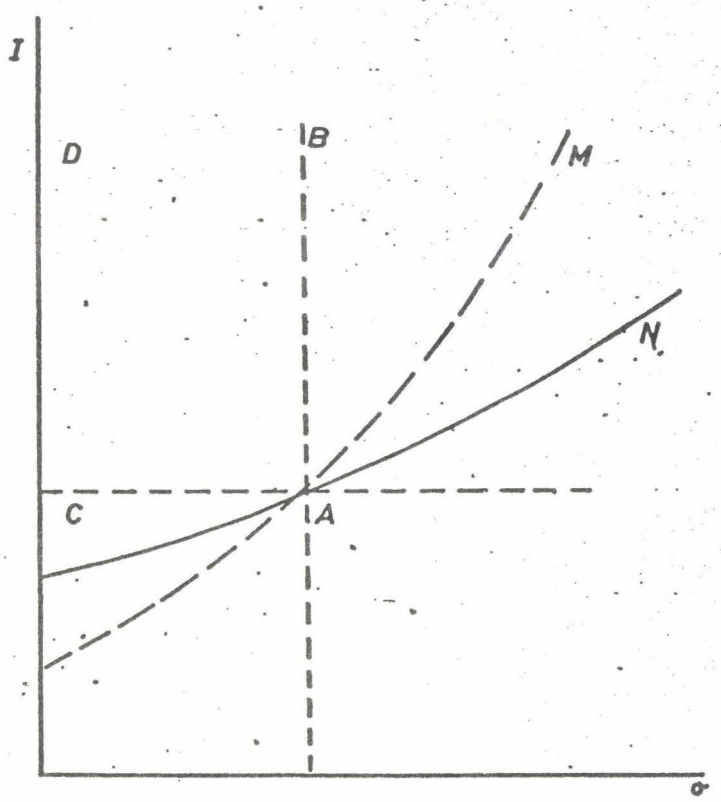
3. If one alternative has a smaller degree of uncertainty and a larger expected equivalent income, it will be preferred.

To illustrate, alternative B in figure 3.1 will be preferred to A under rule 1, alternative C will be preferred to A under rule 2, and D will be preferred to A under rule 3. Thus all alternatives to the NW of A will be preferred to A, but A will be preferred to all alternatives to the SE.

These rules will enable a number of alternatives to be discarded. The NW border of combinations is an efficiency frontier, along which all of the rational choices appeared.

The problem is to decide between alternatives to the NE or SW of each other. To do this requires the owner to hawe an indifference curve that expresses the trade-offs between income and uncertainty. The indifference curve N would be for an owner willing to take

Figure 3.5--Illustration of the comparison of alternatives of expected returns (I) and standard errors of returns (σ).



substantial risks to gain income. A steeper indifference curve would indicate the owner is more conservative, quite willing to sacrifice income for greater certainty.

Since no one knows what the indifference curves of various types of forest owners might be, the analysis at this point can go no further. It will be suggested, however, that the indifference criterion may have the form suggested by Markowitz (1959):

$$k = \log_n(1 + r) - \frac{1}{2} * \left(\frac{2}{1 + r}\right) \qquad (3.30)$$

when k is a level of satisfaction for a rate-of-return, r, and standard deviation, σ. Since rates-of-return are not the preferred financial measure, an indifference curve suggested by Latane and Tuttle (1967) was found more satisfactory. The equation is:

$$k = I^2 - \quad ^2. \qquad (3.30)$$

This type of comparison differs from the procedure in portfolio analysis in that the alternatives all apply to the same production possibility and are exclusive. In portfolio analysis the objective is rate of growth of capital, which is limiting, rather than maximizing returns from another resource--such as a tract of land.

This type of analysis has not been applied before to forest investments, except on a limited basis by Dowdle (1962) and by Marty (1964). Schweitzer (1968) developed a program to compute distributions of rates of return, and tested it in a limited sensitivity analysis using estimated distributions (1970). Thompson and Hayes (1971) have also worked with variation in expected yields using repetitive linear programming runs.

Operational evaluation of alternatives

One objective of this study is to determine as closely as feasible the best combination of choice variables for each level of management and each production alternative. One possible approach is direct mathematical optimization using differential calculus.

For direct mathematical evaluation it would be necessary for the function $\underline{W}$ to be continuous and have first and second order partial deriviatives in the neighborhood of the optimum combination of choice variables. The maximum value would involve solving simultaneously the partial derivatives set equal to 0:

$$\frac{\partial W}{\partial TZ} = \frac{\partial W}{\partial TB} = \frac{\partial W}{\partial EC} = 0. \qquad (3.31)$$

The second order of partial derivatives, when put in form of a Hessian determinant, must have negative minors.

This approach to evaluating forest management regimes is not a realistic means to develop guides for decision-making, for the following reasons:

1. Reducing the available growth, price and cost data to a continuous functional form feasible for direct mathematical solution seems an insuperable task. Most forest management practices are essentially discontinuous. Establishment may involve 1 to 5 treatments, each of which contribute in somewhat different ways to later yields. Indeed, one of the few ways that "envelope" functions could be developed would be repeated simulation with various combinations and selecting the most effective treatment set for each level.

2. The analysis implicitly assumes that the price and cost functions are stable. As will be discussed in Chapters 6 and 7 this assumption is unjustified. A reasonable appraisal of past

in real terms.

3. The operational difficulty for solving the resulting equations for optimum combination of decision variables for each combination of exogenous variables--tract area, site productivity, and condition factors--would be substantial.

There are several alternative approaches to the problem of evaluating timber growing regimes for expected results. One is mathematical programming--linear and dynamic. A variety of researchers (Navon and McConnen, 1968, Clutter, 1968, Clutter and Bampting, 1965, Ware and Clutter, 1971, Thomson, 1969, Curtis, 1962, Coutu and Ellertsen, 1960) have shown that linear programming can be readily applied to allocating land units to alternative management regimes. But the technique is more appropriate for optimizing levels of management for larger properties of numerous units.

Similarly, a smaller group (Arimizu, 1958, Amidon, 1968, Schreuder, 1968 and 1971, Hool, 1970) have applied dynamic programming to stand development problems. But the necessity of defining a relatively few states for each age restricts the pattern of development and introduces substantial "lumpiness" to the solutions.

The approach used in this study employs simulation of stand development of stands by using the growth, price and cost functions available. Though several investigators have devised simulation programs for stands (Botkin, Janek, and Wallis, 1970) and large properties (O'Regan, Arvanitis, Gould, 1966), the evaluation features of their models are limited. They are not stochastic.

Summary

This chapter presents the model of forest management on a tract level, including growth, price and cost functions. Mathematical means to evaluate the model are presented, and solved for one variable. But this approach appears inapplicable for the data available for realistic management levels, and for determination of the uncertainty of returns. The most applicable approach for all purposes is stochastic simulation.

Chapter 4

TIMBER GROWING FINANCIAL RETURNS SIMULATOR

To determine effects of a variety of factors and levels of management on financial returns from timber growing, this study developed a general timber growing financial returns simulator. This computer program simulates hypothetical schedules of costs and returns according to the model presented in Chapter 3 and specified initial data. Essentially this program incorporates the dynamic, stochastic model of the timber growing system developed in Chapter 3 so that experiments on the model can be performed.

Again, the viewpoint is that of an individual forest owner who has or employs professional forestry skills to manage his land. The basic knowledge required by the program inputs is what a professional forester could determine about a timber growing opportunity. The variation in his estimates of yields, prices, and costs is approximated by special techniques to be developed in later chapters.

This chapter describes the plan of the simulation model in general, the major components, and how the components fit together. Detailed development of functions for costs, physical yields, output values, risks, taxes will be described in detail in chapter 5 to 9 respectively. The results of the use of simulator will be discussed in Chapter 10.[1/]

1/ For convenience and shortened expression, the actual computer program is referred to as TIMSIM. The program is written in basic FORTRAN IV universal computer language, and incorporates concepts from general computer simulation system SIMSCRIPT (Kiviat and Colker, 1964), and subroutines for probability functions and random number generation from the IBM Scientific Subroutine Package (IBM, 1968).

Purposes of the simulator

The TIMSIM model is programmed so that a number of trials can be performed in a given program run. A trial is a simulation run on a single stand or stands in one ownership, under specified initial conditions, decision rules, or other parameters. Three types of problems were envisaged:

First, the program was specifically designed for sequences of trials to test the sensitivity of financial returns to the following parameters:

Prices and cost levels and trends

Area of tract

Length of rotation and level of growing stock to be maintained after thinning

Initial stand attributes or conditions of age, basal area density, diameter, and hardwood components

Owners guiding rate of interest and tax situation

Second, TIMSIM can simulate trials with stochastic variation in any or all of the above factors and conditions. The variation may be set initially for a trial and maintained through various periods, or changed from period to period. Stochastic simulation can measure the effects of uncertainty in site estimation, diameter growth, costs, prices, and losses from fire, storm, insects, and disease.

Third, the program can simulate the most likely development of a series of case examples, such as individual Forest Survey plots or actual stands encountered in a forestry program. This type of run was not made for this study.

A major and essential portion of the model is economic evaluation of the results of each simulation trial. Within the program the results of each simulation trial are reduced to present net worth and to rate-of-return on investment. One option, used largely for checking initial runs and evaluating modifications of a trial, links into a universal rate-of-return program previously written by the author (Row, 1970), or other more comprehensive evaluation programs such as NCSUBPR, written by Dennis Schweitzer (1968).

A further purpose for developing the timber simulation model was to provide an improved and accurate means to develop, screen, and initially evaluate management regimes for planning of large areas such as National Forests. Results of TIMSIM can be used as input to management planning programs written by Navon (1971) and Sassaman, Holt, and Bergsvik (1972).

The simulator concept

The TIMSIM program is a specialized production simulation model. As with any other model, the purpose is to abstract from reality those essential characteristics and relationships of the situation into a simpler structure for predicting logical consequences. The model enables the user to determine how one or more changes in initial conditions or relationships would affect other aspects of the modeled system as a whole. In the construction of any simulation model, however, there is a conflict between realism and simplicity (Naylor, Balinfy, Burdick, and Chu, 1966). The model should resemble reality close enough to be useful,

but should not be so complex that it is impossible to understand and manipulate.

Basic components and terminology

It is useful to describe how TIMSIM operates both in conventional simulation and in forestry terms.[2/] This may help the presentation of the remainder of this chapter.

1. Elements or entities in the model are (a) stands of timber, located on particular tracts of land belonging to individual owners, and (b) the owner. In a sense, a third element is the collection of outside forces that determine losses from fire, storm, insects, and disease. In applications of the program covered in this study, only one stand of timber on a single tract is considered in a simulation trial. The model has the capability, however, of considering ownerships composed of several stands. Timber stand elements are temporary in that they are created and destroyed by the model. The owner is assumed in this study to be fixed.

2. Attributes, or descriptive variables of timber stands are primarily area, site productivity, stand age, average diameter, and total height, and on a peracre basis, basal area, number of trees, volume, and value. Attributes of the owner are his guiding interest rate for investment, and several items that determine his tax situation--corporate or noncorporate form, and marginal federal and state income

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2/ The simulation terminology in this section leans heavily on that of SIMSCRIPT (Kiviat and Colker, 1964), and GASP (Dimsdale and Markowitz, 1964).

tax rates.

3. Processes in the model are changes that take place in a stand of timber from selfgenerated biological growth, such as in height or diameter, or from outside forces such as fire, storm, insects, or disease. Each process has three aspects: (a) the probability that it will occur, and if it does, (b) amount of change in the attributes of the stand, and (c) the standard error of the change in the stand. The probability that height and diameter growth will occur is 1.0, though the expected rate and its certainty varies.

4. Events are interactions of the elements of the model--the stand with its owner and with outside forces that determine losses from fire, storm, insects, and disease. The owner determines whether the stand is to be: (a) left alone to grow, (b) partially cut or thinned, (c) improved by removal of cull trees, or (d) harvested and regenerated. The outside exogenous forces determine whether the stand will suffer losses. For any single problem decisions are made and the events occur at a specified fixed interval or within the periods between the intervals. This study uses 5-year periods.

5. Decisions rules are guidelines built into the model or specified as inputs. They determine how the owner will decide on which event will take place. These decision rules may be arbitrarily set at the beginning of a trial, such as a predetermined rotation age, or may be dependent on the attributes of the elements, or may be dependent on a suboptimum intervaltointerval evaluation of benefit/cost, annual income, or rate-of-return measure.

6. Values produced by the timber growing simulation are volume

and value of timber cut. These output variables are evaluated by the last section of the model.

Sequence of operations

For each trial, the program follows a sequence of operations. A flow chart of these operations is shown in figure 4.1. SIMTIM is programmed to:

1. Read basic costs, price and factor assumptions, and parameters that control the sequence of sensitivity progressions or the variation to be generated.

2. Read yield table information if a yield table is used to compute growth and yield.

3. Read initial stand age, volume, and other necessary descriptive attributes of case examples, if required by problem.

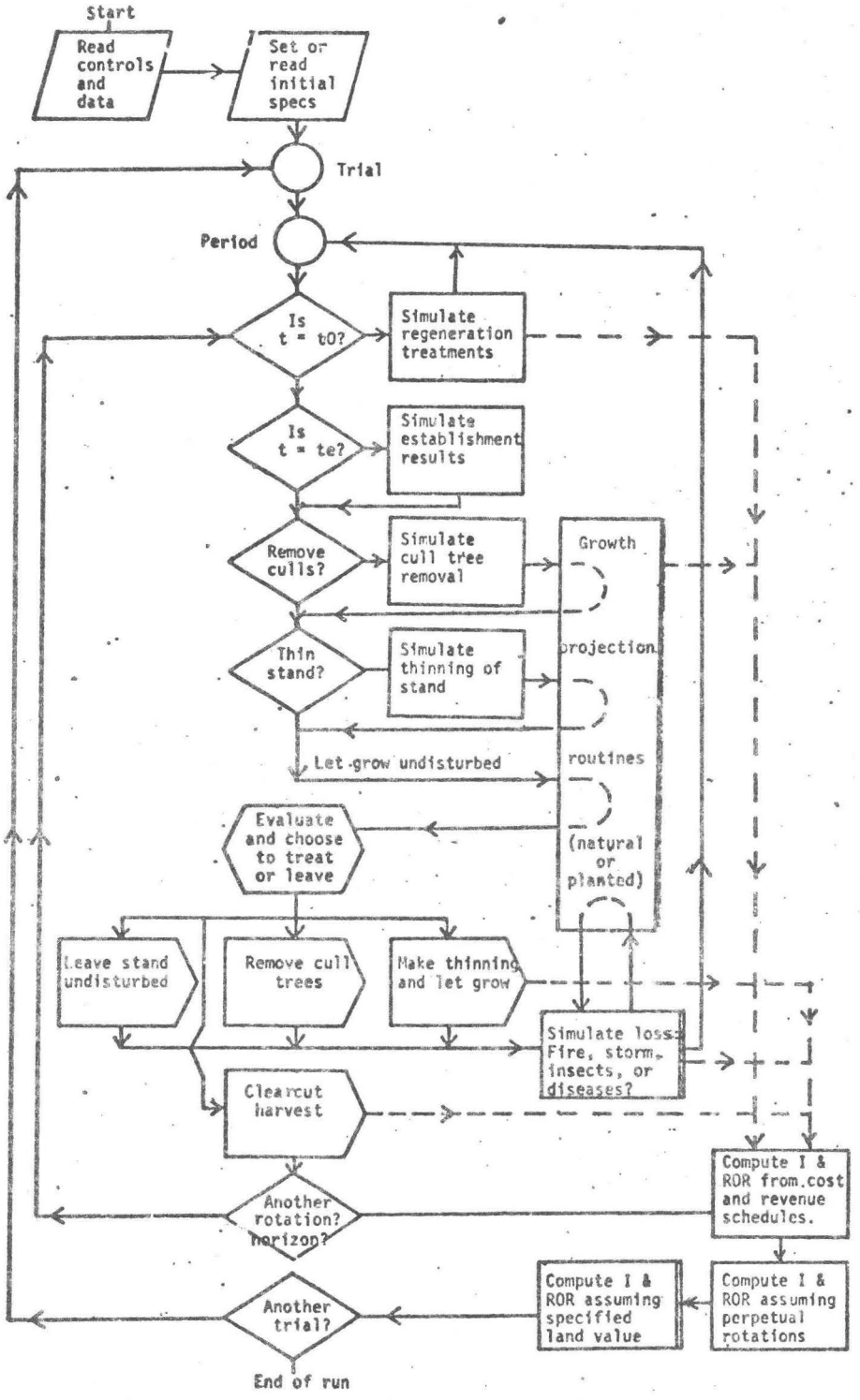
4. Simulate establishment of a forest stand, including establishment treatments and results if the trial starts with bare or cutover land.

5. Simulate physical development of the forest stand. This involves several steps:

a. Simulate provisional changes that would be made in the stand at time (T) by (i) thinning, (ii) removal of cull trees, or (iii) both, according to predetermined specifications, if these alternatives are permitted by controls.

b. Project the growth and development of the stand for a specified period assuming no cutting and each of the alternatives simulated in (a) above. An additional alternative, complete cutting

Figure 4.1--Schematic diagram of the TIMSIM stochastic simulation system developed for this study.



and regenerating the stand, does not need growth simulation.

c. Determine increments and rates of increase of total value for each alternative in (b).

d. Decide on the alternative to be implemented, following decision rules.

e. Implement the decisions by changing the stand according to the tentative simulations of (a), leaving the stand uncut (program will go to step 6), thinning the stand, or regenerating the stand (program will go to step 8).

6. Estimate, if the controls specify, the probability that the stand will suffer from major change in the ensuing growth period by (i) fire, (ii) storm, (iii) insects, or (iv) disease, if the stand is either left uncut or partially cut. By random process, determine if such a loss occurs. If the stand is affected, simulate the changes in stand volume and descriptors.

7. Grow the stand according to the projections made in (5), modified by any losses in (6). Result is the stand at time point (T + 1). Return to step (5).

8. Return to step (4), if the stand is regenerated, unless (i) the controls specify that the rotation is arbitrary ended at a given age, or (ii) the end of the specified time horizon has been reached. If the rotation specified is less than the time horizon, the stand is regenerated and another rotation begins. If the end of the time horizon has been reached, the program will go to step (9).

9. Accumulate total yield in merchantable units, and a schedule of costs and returns for the trial. According to controls, this

may or may not be written on a separate output file.

10. Determine expected financial returns from trial by various measures--equivalent annual income, present net worth, and rate of return. Perpetual rotations may be assumed and land values may be included.

11. Perform similar trials until the end of the specified program run.

12. Compute mean equivalent annual incomes and their variances for problems in which the trials only differ by random variations.

Investment, rotation, and stand ages

An aspect that may cause confusion is the handling of time or various types of "age". The program distinguishes between three types of age:

1. Investment age starts at trial initiation and continues period-by-period until a maximum investment horizon is reached. The length of each period is specified in whole years. All returns and benefits are discounted back to investment year 0.

2. Rotation age starts when the previous stand of timber is cut. Establishment results are estimated at a specified rotation age (10 years old in this study). Stands are examined for management action then and at least every period thereafter. A maximum rotation age may be set at which the stand must be clearcut. Harvest may be set to be dependent on period-to-period rates of value growth or financial measure. A minimum rotation age before which the stand may not be clearcut may be specified. Similar maximum thinning

ages may be specified. A trial may last only one rotation, or last for a number of rotations. The program now can handle 30 time periods, though that could be increased.

3. Stand age, or average age of dominant and codominant trees, may differ from rotation age in that regeneration may be delayed for several years. For natural and planted stands that follow clearcutting, regeneration treatment may be delayed for one or more years. Average stand age may be delayed further. These adjustments to rotation age must be specified.

For certain simulations it may be desirable to simulate the stands only between certain year intervals, say between years 30 and 60 at 10-year intervals, it being unnecessary to concern earlier or later years.

Simulator components

A number of individual components of the program system are important for understanding the operation of the simulator. These are briefly described in this section.

The input routine

Program control, cost, price and factor information is specified in a deck of problem control cards. If the control cards indicate that a yield table is to be read, cards for each period are read. The program can also read specific stand and owner attributes for each trial within a problem.

Simulation trial control

A vital function of the program is to systematically or randomly vary stand attributes, prices, costs, or policy factors for successive trials.

In each successive trial one or more factors may:

1. Increase in arithmetic progressions according to a specified increment, within a range from low to high values.

2. Increase in geometric progressions by a specified number of intervals within a range. This tests sensitivity to factors whose range is particularly wide, such as tract size.

3. Vary randomly within a normal distribution specified by a mean and standard deviation. Such tests will determine the effects of expected factor variations on the financial returns.

If the factors do not vary, normal values specified by the input are used. As explained in the discussion of input, stand attributes factors may be set by reading input cards for each trial.

Trial control functions appear in three sections: (a) at program start, (b) before each trial to set factor values for each trial, and (c) within each trial to set stand attributes when the stand is regenerated or becomes merchantable.

Stand regeneration

Stand establishment consists of three phases:

Treatment. Treatments may be specified to assure regeneration. These are: (a) type conversion to eliminate an unwanted and unmerchantable existing stand, (b) site preparation to reduce slash from logging, interfering brush, and expose mineral soil, ((c) planting

of nursery grown seedlings either by hand or machine, and (d) spraying for hardwood brush control. Each may be simulated separately or in combination. The procedures for estimating costs are described in Chapter 7.

Establishment.--The program may assume "median" regeneration, or the degree of success that would occur at least 50 percent of the time, using initial values from natural stand or plantation yield studies. Or the program can simulate stand regeneration and the resulting stand establishment results using a probabilistic approach. Separate subroutines simulate establishment of: (a) natural regeneration and (b) planting nursery grown seedlings.

The type of treatment influences the degree of regeneration success expected. The routines that estimate stand establishment, STOCK for natural regeneration, and PLANT for planting, are described in Chapter 6 on biological growth models.

Since inadvertent establishment of undesirable species (in this case all hardwoods) is important at less intensive management levels, the program uses a separate procedure for approximating the amount of hardwood incursion at age 10.

Post-establishment treatment.--If specified, the regeneration success may be examined for 2 types of failure: too few trees or too many. If too few, repreparation of the site and reestablishment of the stand can be simulated at a one planning period delay. If too many trees are established, precommercial thinning may reduce the number and improve subsequent stand development, if specified.

Cultural treatments

For established stands, the program can simulate three types of cultural treatments other than clearcut harvesting. At the beginning of each period after the stand is considered established (age 10 in this study), the program will consider:

Commercial thinning, with the smallest trees in the stand individually marked and cut. This is professionally described as "thinning from below." A subroutine estimates the number and average diameter and height of trees needed to be cut for any specified reduction in basal areas. The computational procedure is adapted from Myers (1968), and is described in the following chapter on biological models. The thinning simulation results are provisionally stored after the value of the material to be cut is estimated.

Three variables control this thinning. An upper age limit above which the stand must be thinned, a lower age limit below which the stand cannot be thinned, and a basal area guide to which the stand is thinned. Such a thinning is made only if the expected value exceeds the marking cost.

Hardwood removal. In managed stands of pine timber in the South, volunteer hardwood trees are either unmerchantable or have such low value they are considered undesirable.

Three types of hardwood treatment may be specified to occur under various circumstances:

1. Since hardwood trees are small below the age of 15, usual practice removes them by spraying with selective herbicides.

2. Large hardwoods in older stands are most effectively

removed by injecting herbicide into each tree at the root collar.

3. Controlled burning, each 5-year period, kills completely or the upper stems of small hardwoods and brush. Burning also reduces fire hazard.

It is assumed that the first two treatments are 100-percent effective, though usually some hardwoods will survive. Each controlled burning treatment reduces the hardwood basal area by half if started by age 15. If the thinning alternative is also simulated, cull removal is assumed to be in addition to thinning.

Growth projection

The subroutine for growth can be modified to project stand attributes from one time period to another in any way that requires only the stand attribute data in the system. The subroutine GROW presently includes four methods to estimate growth in subsequent periods. The first, reading values from published timber yield tables is not employed in the study. The second method, projecting growth of thinned plantations, is the same subroutine that estimates plantation establishment (Clutter and Lenhart, 1970). Third, a routine to estimate the growth of undisturbed natural stands is derived from Coile and Schumacher (1960). Fourth, the most applicable growth method of thinned stands uses the basal area growth projection equation based on equations developed by Clutter (1963), modified by judgmental factor. These growth projection relationships are discussed in detail in Chapter 5.

Growth is estimated for a single period for each of the alternatives considered which retain a stand--let it grow, thinning,

and hardwood removal. The stand attributes projected are stored. The price subroutine estimates the price of the timber expected to be received.

Evaluation of alternatives

The alternative chosen at the end of each period can be forced by specification or the program can make a decision based upon the highest value of one of three criteria specified by the owner. The alternatives considered, including clearcut harvesting. Three measures which can be specified: (a) the benefit-cost ratio at the owner's guiding interest rate, (b) the present net worth at the specified interest rate, and (c) the rate of return. For each alternative, benefits or returns are the future value of the stand and land, if any, at the end of the next period, and costs are present values less any return from thinning or plus any costs for precommercial thinning or hardwood removal.

The decision is constrained by the owner's policy parameters. Stands older than maximum harvest age are harvested, and those less than minimum age cannot be. Policy parameters for thinning function similarly.

Implementation of the decision

After a decision is made on which alternative the simulation is to follow, the program must "implement" the decision. A section of the program will alter the stand attributes, enter costs and revenues on the trial record, and accumulate yields, costs, and revenues in summary registers. The program changes several control variables that affect subsequent possibilities, such as whether

the stand has ever been thinned. It is provisionally assumed that the stand will resemble the stand projected by the growth estimation subroutine.

Losses from fire, insects, disease, and storm

The program randomly simulates losses from fire, insects, disease, or storm during the period between decisions. Presently provisions are included for only five types of loss to southern pine, each under the control of input control variables. The losses are discussed more fully in Chapter 8.

1. Fire. Wildfire in the dry summer season can kill all or most of the timber in a stand. It is assumed that fire affects the stand in a manner similar to thinning from below.

2. Storm. Timber stands are subject to either devastating hurricane or tropical storms, along the Atlantic or Gulf coasts, or from severe wind and ice storms in the Piedmont and more northerly sections. These storms generally work in a manner opposite to fire--they act as a thinning from above. In addition the program reduces the quality of the stand.

3. Insects. Southern pine is subject to several types of bark beetle attacks. The probability of attack is increased by previous fire or storm injury, and is affected by the vigor of the trees.

4. Diseases. Two types of disease are simulated by the computer program. First is fusiform rust disease that infects the apical shoots and small branches of young trees, grows down

into the main stem, and causes a complete girdle or canker. The second disease is Fomes annosus root rot that also affects both plantations and natural stands.

Estimation of average losses from these causes would seriously underestimate the impact from these stands, since succeeding growth of only slightly injured stands would in great part compensate for the loss by time of final harvest. The major impacts come from destruction of entire stands, with consequent loss of management costs and opportunities to achieve timber growth.

Thus the program appraises impacts from these losses on a probabilistic basis. For the types of losses to be considered in any run, a subroutine can simulate injury on a random basis. Within each period, the procedure determines the cumulative probability of loss from each cause separately during each period, selects a random number from 0 to 1, and simulates the effects if the random number exceeds the computed probability. Additional random simulation of extent of loss follows. The loss is assumed to occur midway between the periods and is based on the average need period attributes. Action based on the loss, if any is justified, is taken at the beginning of the next management period.

Trial termination routine

A trial can be terminated by several mechanisms. It can end when:

1. The maximum harvest age is reached and the stand must be cut.

2. The stand is otherwise clearcut by application of the criteria of the owner.

3. Total time horizon specified by the input parameters has elapsed. Under this operation a number of rotations or partial rotations may be completed within a given trial.

At the end of each trial a number of control variables must be re-established for a new trial.

Evaluation of resulting schedules

From the information accumulated period by period within a trial a number of statistics for the trial are computed and printed. The summary measures included are:

Total yield during trial.

Average annual yield.

Average volume of growing stock during trial.

Average value of growing stock during trial.

Percent volume yield: Average growing stock volume divided by average annual yield.

Percent value yield: Average annual net revenue divided by average growing stock value.

Total gross revenues during trial.

Total costs of treatments, taxes, and management during trial.

Rate-of-return without land value.

Rate-of-return with land value, if assumed.

Gross revenue, costs, and net revenue are also computed on the

following bases: (a) average annual, (b) discounted for a single trial period, (c) discounted for a perpetual series of trials, (d) equivalent annual income for a single trial period, and (e) equivalent annual income for a perpetual series of trials. Instead of computing values of (c) and (e) for a perpetual series of trials, the program can be instructed to include a final land value at the end of the trial, as discussed in Chapter 3.

Secondary programs

To develop and test the functions used in this simulation program, four additional computer applications were developed.

Biological, cost,and price function test program

Using the main simulation program proved to be an inefficient and expensive way to test the functional subprograms for biological processes and conversions, prices, costs, and losses. A short specialized program was developed to compute functional values for ranges of the argument values.

Loss test program

A separate program was developed to separately simulate occurrence, size, and severity of losses for large number of trials with the identical stand conditions. This provided tests of the probability functions presented in Chapter 8.

Tax impact program

The secondary output schedules produced by the program is suitable input for a secondary program that determines the after tax financial returns and the after tax present net worth, equivalent annual income, and rate-of-return. This program was used as a subroutine to the main program in the simulation of chapter.

Variance function iterative regression program

Simulation models such as constructed for this study include many relationships for estimating (a) attributes or descriptors of entities and (b) probability and extent of changes in attributes caused by various processes simulated. The range in values of most attributes, measured by coefficients of variation, is generally wide. There are also wide ranges in proportions of variance associated with endogenous variables or factors within the simulation system. This proportion, measured by the square of the coefficient of correlation (R^2), varies from .0 to 1.0. The remaining variation is caused by exogenous factors outside the simulation system and therefore considered random.

Several examples may illustrate the diversity in relationships. The function of basal area of a timber stand with average diameter and number of trees is deterministic by definition:

$$B = .005454 * D^2 * N$$

where: B = basal area in square feet per acre

D = average stand diameter (tree of mean basal area)

N = number of trees per acre

The constant, .005454, is $\pi / (2^2 * 12^2)$

A relationship not deterministic but quite precise is that of total cubic volume of the stand on diameter and height of stand. For example:

$$Y = 3.3920 * D^{1.3321} * H^{1.7411} * N$$

where: Y = total cubic volume in cubic feet inside bark

H = total height of dominant and codominant trees in feet

The variance of this relationship, developed by Schumacher and Coile (1960) has an error of less than 5 percent, with an R^2 of .98. Simulation of this error would have little effect on financial returns.

Among those relationships with a modest correlation with other attributes (R^2 from .30 to .65) are the functions that estimate treatment product values and costs. These are to be discussed in Chapters 5 and 7.

At the other extreme are a number of processes that appear to be random phenomena. Among these are occurrences of fires, particularly lightning-caused fires, and ice and hurricane storms. It is likely that these behave much like Poisson processes, with little relationship between the likelihood of occurrence related to attributes of the timber stand. Extent of damage once these events occur, however, is often influenced by stand attributes.

In the biometric research that has developed the functions of timber growth, mortality, and volume, extensive use has been

made of regression analysis. Most studies make the usual assumptions of (a) normally distributed error components and (b) uniformly distributed errors in the dependent variable throughout the expected range of values. Little attention has been paid to determining how well observed data follow these assumptions. Disclosure of standard errors of estimates and coefficients of multiple correlation is usual.

Such regression results are perfectly satisfactory in construction of deterministic models. They produce unbiased estimates of expected values unless the distributions of errors around expected values are quite abnormal and variances change within the range of expected values of Y.

In stochastic simulation models, however, the shape and extent of variation around expected value can be an important factor in determining probability distributions of financial returns and may have substantial impact on the decision made from them.

General discussion of simulation models (Naylor, Balinby, Burdick, and Chu, 1966, Naylor, 1969) emphasize purely random phenomena and their probability distributions, with less attention to determining correlations within the modeling system, which are most often considered as given. Little discussion of these problems in other literature on simulation has been found.

Preliminary work with both the physical-biological relationships, and the cost and price function for this study suggested these problems:

1. Non-normal variation. Expected values for most attributes are not normally distributed around the regression estimates. This is no problem in regression analysis since estimates of coefficients are normally distributed.

But in simulations this may present problems, for example, distributions of periodic growth tend to follow a negative binomial distribution because neither diameter or height growth is even less than 0. Rates of mortality tend to follow a negative exponential distribution. Distribution of both costs and prices tend to have longer tails on the side with the largest value.

In many biometric relationships, use of logarithmic regression forms least partially corrects this bias. The usual form of the total height versus age relationship is a logarithmic, reciprocal one (Schumacher, 1939). Many of the basal area growth functions are also logarithmic (Clutter, 1963; Schumacher and Coile, 1960), and as with number of trees and mortality (Lenhart and Clutter, 1969), and volume (Schumacher & Hall, 1933). This form, however, may impart a bias (Cunia, 1969).

In determining cost and price functions in this study, special analyses of the shape of the distribution of variations from expected value will be made. As explained later, residuals will be computed and corrected for observation weight, and tabulated according to intervals of standard error. Chi-square tests will determine if the residuals conform to the normal distribution.

2. Heteroscedasticity. Another assumption of linear regression analysis is that disturbances are independently distributed with

a constant variance. This also does not generally hold for relationships in this study. Variance in height or diameter growth is generally proportional to expected growth. Fortunately, use of logarithmic relationships in developing the biometric relationships implicitly recognized this. In simulating variation in biometric functions random disturbances were generated in logarithmic units before retransformation to absolute scale. Thus simulated variability is proportional to the expected value.

In cost and price functions in the simulation model, this procedure was not applicable. Constant terms representing fixed costs or loss of value per tract are important factors. Yet on inspection, it was apparent that variance was related to either acreage or expected value.

In other relationships such as the proportion of volume in merchantable sizes, in mortality relationships, where the dependent variable was a proportion between 0 and 1, the variability was proportional to the difference between 0 and 1. In such cases a probit transformation or analysis is indicated.

On searching the available multiple regression programs none was found that met the requirements for simulation modeling regressions. Thus a special multiple regression program was written, or assembled from other programs (IBM, 1968). It has these features:

1. A stepwise multiple regression model with specified T-test criteria for entering and for eliminating variables.

2. All variables including the intercept constant may be forced in, excluded, or entered in order of their reduction of

variance of the dependent variable.

3. Any transformation or rearrangement is permitted for all variables by writing a special "users'" subroutine.

4. The regression can be weighted by a specific logarithmic function of either an independent or dependent variable (V), in which:

$$W = \frac{1}{a * V^b}$$

in which W is the weight, V the variable, and a and b specified constants.

5. The regression can be optimally "self-weighted," by iterative solution. The procedure automatically followed is (a) solution of a preliminary weighted or unweighted regression, (b) calculation of residuals, (c) computing a regression of the variance from the expected value as a function of expected value:

$$V(Y) = a * Y^b$$

(d) using this relation to weight a subsequent iteration of the regression analysis by $W = 1/V(Y)$, and (e) repeat the cycles until the regression coefficients become stable. This procedure both improves the determination of regression coefficients and tests for heteroscedasticity.

6. Tests for departures from normality of variance by a Chi-square test of the residuals. If non-normal, the data are presented for subsequent fitting of a beta or other function.

This program was tested out on standard problems in regression texts (Draper and Smith, 1966), and Williams (1959), and by the test procedure outlined by Wampler (1969).

Summary

This chapter describes the computer programs and techniques used for the simulations in the study. Development of these programs constitute a major portion of the effort and thus were designed for broader use than the immediate applications.

Chapter 5

BIOLOGICAL MODELS OF GROWTH AND DEVELOPMENT OF SOUTHERN PINE STANDS

Of the various forest ecosystems, southern pine forests are known and understood better than any other type in the United States. This chapter describes the sources of biological relationships used and how the model incorporates them.

Variations in research approaches, however, cause numerous problems in combining relationships from different sources. Until recent years, primary emphasis was placed on estimating yields of wood directly in one of several merchantability units. Though such research results were of immediate practical use, concentration on volume instead of height, diameter, and quality growth and tree mortality missed numerous opportunities to develop basic biometric and ecological relationships that would have had long-run use.

The basic modeling approach

Throughout the modeling of growth and development processes in this study, there were many alternative levels of detail of biological processes. A balance had to be maintained between emphasis on biological and economic factors. The guiding rule was to include a refinement in biological processes if it promised to have substantial effects on either costs, yields, or unit value of products, or on the consequences of management decisions.

The simulation system described in Chapter 4 was designed to accommodate several possible basic approaches to projecting growth and yields from forest management. The most important initial decision was to select one for this study.

Criteria for selection

The criteria used to select the most feasible stand modeling method for this study were that it:[1/]

1. Be sensitive to major variables for which basic management decisions must be made, such as length of rotation, basal area to be retained after thinning or cull tree removal and types of regeneration treatments applied.

2. Treat height and diameter growth separately. These two distinct aspects of growth have different effects on volume and value growth over time (Buckman, 1962). This separation allows for more realistic estimation of growth of both thinned and unthinned stands. Of similar importance is direct proportion of mortality.

3. Estimate yields in cubic feet of wood inside bark of the entire stem. Total cubic feet is a biological unit of growth as distinct from commercial measures such as board feet or cords. Subsequent conversion from cubic feet to merchantable units can be modified according to assumed utilization and measurement standards.

1/These criteria differ in important aspects from those advocated by major texts in forest management (Davis, 1966, Spurr, 1952), which continue to emphasize simplicity and direct estimation of physical volume at the expense of realism and measurement of quality.

4. Describe units of yield so that distinctions can be made between quality levels that affect unit values. Minimum information should include average diameter, height, and age of trees cut. A procedure to estimate percent of volume by quality classes is desirable.

5. Estimate variations in the growth and development process stochastically. Direct or indirect indications of the variability of all of the major growth processes are available in the literature.

6. Be adaptable to simulation of losses from fire, insects, disease, and storm. The realism by which this can be done determines whether adequate estimates can be made of financial returns from loss control programs.

7. Have been tested or verified by application to actual individual plots or stands of various densities and ages. Such testing establishes confidence that results are good approximations to the growth and yields that can be obtained in actual practice.

8. Provide the information on output and costs necessary to utilize fully available knowledge of prices and costs.

An additional consideration is cost of operating the simulation program. When simulating a large number of stochastic variations, the trade-off between accuracy of detail and number of trials becomes important.

Approaches considered

The most important approaches and the ways in which they meet the criteria for simulation, are as follows:

Direct yield table or yield equations. Four major sets of yield tables exist for either loblolly, or for all the southern pines: USDA's Miscellaneous Publication 50 (1929), McKinney and Chaiken (1939), Meyer (1942), and Schumacher and Coile (1960). All presume full or normal stocking, which is greater than the level of stocking advocated in forest management guides or the stocking that is probably economically desirable. Only Schumacher and Coile provide a tested procedure for estimating growth for stands of less than full stocking. This is discussed right below. Otherwise these tables, or interpolations of them, do not meet criteria 1, 2, 5, 6, and 8 though most meet criteria 3, 4, and 7.

Aggregate stand projection. This procedure treats the timber stand as one, or only several classes of trees, and projects changes in (a) age, (b) number of trees, (c) total height, (d) average diameter, (e) total basal area, and (f) total cubic volume. It is generally applicable only to even-aged stands. Most past and current research on growth and yield response to thinnings and other treatments employs aggregate stand procedures. Projection techniques for southern pine using this level of detail were developed by Schumacher and Coile (1960), Clutter criteria 1, 2, 3, 5, 7, and 8. Lack of detail on distributions of trees by diameter and quality classes limits the potential for number of researchers have shown that diameter classes for even-age stands can be estimated from the five descriptive attributes (Bailey and Dell, n.d.).

Diameter class or "stand table" projection. This technique keeps track of the distribution of trees among diameter and sometimes quality and species classes, and estimates growth and mortality separately by class. Movement of trees between classes at subsequent time periods is simulated period by period. Long used in forestry, Wahlenberg (1941) elaborated on the technique extensively. A computerized version called The Timber Resource Analysis System (TRAS) developed by Larson and Goforth (1970) has been adopted for updating forest resource inventories and projecting regional timber supplies.

The approach, as developed in TRAS, requires extensive input data detail, including smoothed distributions of trees among diameter classes and rates of growth and mortality by diameter class. Ideally, the method should employ functions that estimate diameter growth by age, stand density, and site index as well as present diameter. But these functions have not been developed or tested on individual timber stands in the South. Another major weakness is that TRAS does not estimate height growth but implicitly includes change in average height in tables of volume by diameter class. It does not appear possible to incorporate available information on growth variability of individual stands without extensive reprogramming and developing methods to estimate growth variation by diameter classes.

Thus diameter class projection does not meet criteria 1, 2, 5, and 7 at present. But with substantial additional research and development, stand table projection is potentially superior to aggregate stand analysis in describing quality of yield and simulating the impact of agents that cause losses of yield--criteria 4 and 6.

Tree-by-tree projection methods. This approach further

disaggregates components of forest stands. Each sample tree represents a given number of trees in the forest. Functions estimate growth, mortality, and other processes for each sample tree. Development of these functions has proven so far to be extremely difficult, even with sophisticated biometric research. However, once developed, the approach would employ all of the opportunities presented by high-speed computers with large memory storage. Programming of biological processes of individual trees is currently underway at various research institutions.

Approach selected

The approach selected for this study as most suitable and flexible was aggregate stand simulation in which the stand is described by five attributes: age, number of trees, height, diameter, basal area, and volume. Developed computation techniques could be developed to meet all but two of the criteria well, and produce approximations for the other two (4 and 6). Until better quantification of growth and mortality processes in forests are available, the aggregate stand appears to be the most practical basis for management and economic simulation.

Stand establishment

Of the major aspects of stand growth and development, the first in the sequence of a rotation is stand establishment, or more loosely, stand "birth" or regeneration. Three aspects of establishment are important: surviving number of trees, basal area, and height. Initial number of trees and basal area are treated in this section. Height is discussed in the section on height growth.

The two general modes of regeneration, natural and planted, produce

strikingly different stands with the same species on the same type of land. Even early differences in survival and spacing within each mode persist throughout the life of the stand, though they may be disguised by thinning.

Natural stand regeneration

In even-aged management, regeneration comprises germination and establishment of seedlings on forest land. Regeneration requires the presence of a source of seed, so that sufficient amounts of seed reach the seedbed within a year or two of removal of the previous stand or other vegetation. In addition to seed, regeneration requires a mineral seedbed, freedom from heavy pine or hardwood cover, and from brush. Seed production of loblolly varies widely, with adequate crops only in a portion of the years. In years of low production little seed may germinate because: (a) a high proportion may not be viable (b) consumption of birds and rodents and (c) grazing. Fortunately bumper seed crops may be predicted a year in advance, and harvest cuts scheduled accordingly (Wahlenberg, 1960).

If a harvested pine tract is controlled burned previous to a large seed crop and clearcut harvest, enough seed may be in place to assure adequate regeneration. If the tract or an abandoned field is within 300 to 400 feet of a mature stand of loblolly pine, at least fair regeneration occurs in 5 years (McQuilkin, 1939). This study assumes that either of these conditions are present for the stands.

Otherwise two other treatments are usually effective in securing regeneration from seed. First, from 3 to 10 mature seed trees over

10 inches in diameter may be left to seed in the area. A portion of the value of these trees are lost because of the additional cost of seed tree removal. Second, the area may be direct seeded with seed coated with a bird and rodent repellant. The cost of direct seeding is only a fraction of the cost of planting. The results closely resemble that of good natural regeneration, with a high probability of very dense reproduction. If these treatments are included in the management regime, the annual income would be reduced slightly.

The result of regeneration is establishment of seedlings, or at later stages, "sapling" trees. Stocking can be measured in several ways.

1. Number of trees (N) alone is unsatisfactory because trees are not uniformly spaced--some areas with clumps of competitive trees, other areas bare of trees and not contributing to forest growth. Criteria for including a tree in the total count differs by stage of stand development and yield method. In established stands, only saplings--trees 1-inch or more in diameter at 4.5 feet (diameter breast high or DBH)--are generally counted.

2. Basal area in square feet (B) can measure stocking after the crowns of trees in a reasonably well-stocked stand begin to close at age 5 to 10. In even-aged stands, the basal area that represents full stocking increases as the stand becomes older and the trees larger.

3. Various stocking indexes (S) have been devised to measure the proportion of area effectively covered with trees (Reinake, 1933; Chisman and Schumacher, 1940; Stahelin, 1949; Nelson and Brender, 1960). In most of these methods "full stocking" at any age is regarded as the highest practical occupancy of the land by trees.

Since all three measures are required in various aspects of the simulation model, regeneration is estimated in both number of trees and basal area at age 10. From these stocking index is computed by the procedure developed by Schumacher and Coile (1960). At this time, no more additional trees that would reach commercial size would be expected, the crowns of the trees would have largely grown together, and the stand would be ecologically a forest community.

Factors influencing stocking of naturally regenerated stands are presence of seed source, preparation of site to expose bare soil, presence of inhibiting slash, brush, or other vegetation, and weather factors affecting size of seed crop and rates of germination and early seedling survival. Also of major concern for southern pine are Pales weevils, fusiform rust infection, and seed and seedling-eating birds and rodents.

No probability relationships of natural pine establishment could be discovered in the few literature references to successful stocking after natural regeneration. Interim probability distributions were developed to describe the available data on number of trees and basal area to be expected. These were based on the following information.

Number of trees. In management of even-aged stands in the South, a fully stocked regenerated stand has 3,000 or more seedlings at age 5, with 80 percent of sample milliacres with at least one seedling or sapling present (Trousdale, 1950; Wahlenberg, 1960). By extrapolation backward the functions for number of trees and basal area in Schumacher and Coile's study for site 80, a stand of 100 percent stocking would have more than 5,000 saplings of 35.6 square feet basal area at age 5. The basal area of a fully stocked stand increases to 65.6 at age 10, while numbers of trees drop to 1,500.

Timber Resources for America's Future (USDA Forest Service, 1958) reports a survey level of management which rates potential productivity by stocking after cutting. The standards for adequate regeneration in the South was 1,000 existing or potential seedlings per acre of commercial species. Tracts with 70 or more percent of this standard were classified as in the upper level of management, from 40 to 70 percent as medium, and less as poor. The stocking they found on lands cutover within the period 1947-53 is as follows:

	Percent of recently cut areas with:		
Owner class	700 or more trees	400 to 700	Less than 400
Small private	48	33	19
Medium & large private	77	17	7

From this information a rough estimate of a regeneration probability distribution could be made. Estimating stocking appeared more feasible at age 10, when competition has reduced number of trees and occupancy of site more uniform than at earlier ages. The equation that fitted the data best assumes a logarithmic form for the number of trees (N) for a given cumulative probability (P) expressed in decimals. Thus the number of trees at age 10 for well prepared site 80 land may be expressed:

$$\log_{10}(N_{te}) = b_0 + b_1 * \log_{10}(E + .1) + b_2 * \left(\frac{1}{1.01 - E}\right) \quad (5.1)$$

The data used to fit the equation are marked with asterisks in table 5.1. Solving the simultaneous equations produced the following estimating equation:

$$\log_{10}(N_{te}) = 3.22462 + 2.23610 * \log_{10}(E + .1) + \left(\frac{.01160}{1.01 - E}\right) \quad (5.2)$$

Solutions to the equation for other values are also shown in table 5.1. It is only at very high probabilities that number of trees exceed 2000.

Basal area. The literature sources indicates that in recently established stands fewer trees do not reduce basal area stocking proportionately. Each tree has more room to grow and less competition from other seedlings and saplings. It was estimated that basal area expected 70 percent of the time would be approximately half that of Schumacher and Coile's full stocking, with a minimum stocking under the worst conditions. Fitting these data to an equation form of:

$$B_{10} = b_0 + b_1 * (E + .1) + b_2 / (E + .1) \qquad (5.3)$$

yields the equation:

$$B_{10} = -2.4862 + 76.0187 * (E + .1) - 0.2615 / (E + .1)$$

Solution of this equation produces the estimates of basal area stocking at 10 years shown in table 5.2. The diameters appear in table 5.3.

Effect of site preparation. Good seedbed at regeneration may be considered a clearcut area relatively free of slash which has been prepared mechanically with disking within a year or two of timber harvest. For other seedbeds the number and seedlings may differ substantially. According to Trousdale (1950), treating the area only by prescribed fire may halve the number of seedlings. Without site preparation, lack of exposure of mineral soil and competing brush and slash would substantially reduce the number further. Based on his estimates, factors were constructed to express the effect of different seedbeds:

Table 5.1--Number of trees in natural loblolly pine stands at age 10, by probability of regeneration and site index.

Cummulat. Probabil.	Site Index 60.	70.	80.	90.	100.
(Decimal)	(Trees per Acre)				
	Site Factor = 0.				
0.0	16.	12.	10.	8.	7.
0.1	74.	58.	47.	39.	34.
0.2	185.	145.	117.	98.	83.
0.3	354.	277.	224.	187.	159.
0.4	586.	458.	372.	310.	264.
0.5	888.	695.	564.	470.	401.
0.6	1270.	994.	806.	672.	573.
0.7	1748.	1368.	1110.	925.	789.
0.8	2371.	1855.	1505.	1255.	1069.
0.9	3368.	2636.	2138.	1783.	1519.
1.0	47258.	36982.	29998.	25014.	21320.
	Site Factor = 2.				
0.0	8.	6.	5.	4.	3.
0.1	36.	29.	23.	19.	16.
0.2	91.	71.	58.	48.	41.
0.3	173.	136.	110.	92.	78.
0.4	287.	225.	182.	152.	130.
0.5	435.	341.	276.	230.	196.
0.6	622.	487.	395.	329.	281.
0.7	857.	670.	544.	453.	387.
0.8	1162.	909.	737.	615.	524.
0.9	1650.	1291.	1048.	874.	745.
1.0	23156.	18121.	14699.	12257.	10447.
	Site Factor = 4.				
0.0	4.	3.	2.	2.	2.
0.1	18.	14.	11.	9.	8.
0.2	44.	35.	28.	24.	20.
0.3	85.	66.	54.	45.	38.
0.4	141.	110.	89.	74.	63.
0.5	213.	167.	135.	113.	96.
0.6	305.	239.	194.	161.	138.
0.7	420.	329.	266.	222.	189.
0.8	569.	445.	361.	301.	257.
0.9	809.	633.	513.	428.	365.
1.0	11347.	8879.	7203.	6006.	5119.

Table 5.2--Basal area in natural loblolly pine stands at age 10, by probability of regeneration and site index.

Cummulat. Probabil.	Site index 60.	70.	80.	90.	100.
(Decimal)	(Basal area in square feet per acre)				
	Site factor = 0.				
0.0	2.4	2.4	2.5	2.6	2.7
0.1	10.7	11.1	11.4	11.8	12.2
0.2	18.3	18.9	19.4	20.1	20.7
0.3	25.7	26.4	27.3	28.1	29.1
0.4	32.9	33.9	35.0	36.1	37.3
0.5	40.2	41.4	42.7	44.1	45.5
0.6	47.4	48.8	50.4	52.0	53.7
0.7	54.6	56.3	58.0	59.9	61.9
0.8	61.8	63.7	65.6	67.7	70.0
0.9	69.0	71.1	73.3	75.6	78.1
1.0	76.2	78.5	80.9	83.5	86.3
	Site factor = 2.				
0.0	1.3	1.4	1.4	1.5	1.5
0.1	6.0	6.2	6.4	6.6	6.8
0.2	10.3	10.6	10.9	11.3	11.7
0.3	14.4	14.9	15.3	15.8	16.4
0.4	18.5	19.1	19.7	20.3	21.0
0.5	22.6	23.3	24.0	24.8	25.6
0.6	26.7	27.5	28.3	29.2	30.2
0.7	30.7	31.6	32.6	33.7	34.8
0.8	34.8	35.8	36.9	38.1	39.4
0.9	38.8	40.0	41.2	42.5	44.0
1.0	42.8	44.1	45.5	47.0	48.5
	Site factor = 4.				
0.0	0.7	0.8	0.8	0.8	0.8
0.1	3.4	3.5	3.6	3.7	3.8
0.2	5.8	6.0	6.2	6.4	6.6
0.3	8.1	8.4	8.6	8.9	9.2
0.4	10.4	10.7	11.1	11.4	11.8
0.5	12.7	13.1	13.5	13.9	14.4
0.6	15.0	15.5	15.9	16.4	17.0
0.7	17.3	17.8	18.4	18.9	19.6
0.8	19.6	20.1	20.8	21.4	22.1
0.9	21.8	22.5	23.2	23.9	24.7
1.0	24.1	24.8	25.6	26.4	27.3

Table 5.3--Average diameter of trees in natural loblolly pine stands at age 10, by probability of regeneration and site index.

Cummulat. Probabil.	Site index 60.	70.	80.	90.	100.
(Decimal)	(Diameter in inches)				
	Site factor = 0.				
0.0	5.2	6.0	6.8	7.5	8.3
0.1	5.1	5.9	6.7	7.4	8.2
0.2	4.3	4.9	5.5	6.1	6.8
0.3	3.6	4.2	4.7	5.3	5.8
0.4	3.2	3.7	4.2	4.6	5.1
0.5	2.9	3.3	3.7	4.1	4.6
0.6	2.6	3.0	3.4	3.8	4.1
0.7	2.4	2.7	3.1	3.4	3.8
0.8	2.2	2.5	2.8	3.1	3.5
0.9	1.9	2.2	2.5	2.8	3.1
1.0	0.5	0.6	0.7	0.8	0.9
	Site factor = 2.				
0.0	5.6	6.4	7.3	8.1	8.9
0.1	5.5	6.3	7.1	7.9	8.7
0.2	4.6	5.2	5.9	6.6	7.2
0.3	3.9	4.5	5.1	5.6	6.2
0.4	3.4	3.9	4.5	5.0	5.5
0.5	3.1	3.5	4.0	4.4	4.9
0.6	2.8	3.2	3.6	4.0	4.4
0.7	2.6	2.9	3.3	3.7	4.1
0.8	2.3	2.7	3.0	3.4	3.7
0.9	2.1	2.4	2.7	3.0	3.3
1.0	0.6	0.7	0.8	0.8	0.9
	Site factor = 4.				
0.0	6.0	6.9	7.8	8.6	9.5
0.1	5.9	6.8	7.6	8.5	9.4
0.2	4.9	5.6	6.3	7.0	7.7
0.3	4.2	4.8	5.4	6.0	6.6
0.4	3.7	4.2	4.8	5.3	5.8
0.5	3.3	3.8	4.3	4.8	5.2
0.6	3.0	3.4	3.9	4.3	4.8
0.7	2.7	3.2	3.6	4.0	4.4
0.8	2.5	2.9	3.2	3.6	4.0
0.9	2.2	2.6	2.9	3.2	3.5
1.0	0.6	0.7	0.8	0.9	1.0

Seedbed condition	Factor (Sf)
Old field	0
Cutover or converted site preparation	0
Intensive site preparation	2
No site preparation	4

These factors are assumed to affect the number of trees and the basal area according to the following relationship:

$$N_{10b} = N_{10a} * .70^{Sf} \quad (5.4a)$$

$$B_{10b} = N_{10a} * .75^{Sf} \quad (5.4b)$$

where N_{10b} and B_{10b} are estimated number of trees and basal area for the site in question, and N_{10a} and B_{10a} are estimates for sites with standard site preparation factor of 0.

Regeneration by planting

The other mode of regeneration is planting nursery grown seedlings by hand or machine. Planting loblolly or other southern pines has several advantages:

1. Uncertainty of regeneration success is reduced.

2. Uniform and near optimum spacing creates fast growth up to the time the crown closes. Little growth up to age 15 is lost due to mortality.

3. Improved genetic stock can be introduced that has superior growth and quality.

4. Thinnings in plantations can usually be made earlier since the dominant and codominant trees reach merchantable size at a younger age.

When planting southern pines started in the 1930's and 1940's, most plantations were established on old fields. Only in the last 15 years have pines been planted extensively on cutover stands in lieu of natural regeneration. Consequently nearly all plantation yield studies are of old-field stands. Wide experience has shown, however, that in plantations on cutover land survival is less, and both height and diameter growth is somewhat greater than in plantations on old fields. To allow for these factors in computing yields, plantation age was reduced one year based on judgement of experienced foresters.

Number of trees. Rate of survival in a plantation has been found to be a function of age and number of trees planted. With increasing age and planting density, cumulative mortality increases. Lenhart and Clutter (1971) found that survival can be predicted as follows:

$$\text{Probit (P)} = 9.3745 - .67637 * \log_{10}(T) - .96269 * \log_{10}(N_0)$$

where Probit (P) is the probit transformation of survival rate, T is plantation age, and N_0 is number of trees planted. Since the standard error of the probit transformation in the analysis was .448, the cumulative probability of expected number of survivors of a 500 tree per acre plantation at age 10 can be computed. It is shown in Table 5.4.

Basal area. Basal area estimating procedures for plantation were also developed by Lenhart and Clutter (1971). They use a beta function to describe the distribution of basal area according to diameter class. The involved procedure for computing the values is programmed into SIMTIM. The area under the beta function is subdivided into segments. Trials of different increments showed that at different ages, site indexes, and number of trees, estimates of B and Y rapidly converged on stable values

Table 5.4--Number of trees in loblolly pine plantations at age 10 by probability of regeneration and site index.

Seedlings	Site index				
	60.	70.	80.	90.	100.
(Number)	(Trees per acre)				
	Site factor = 0.				
300.	272.	272.	272.	272.	272.
400.	353.	353.	353.	353.	353.
500.	432.	432.	432.	432.	432.
600.	508.	508.	508.	508.	508.
700.	582.	582.	582.	582.	582.
800.	653.	653.	653.	653.	653.
900.	723.	723.	723.	723.	723.
1000.	791.	791.	791.	791.	791.
1200.	922.	922.	922.	922.	922.
1400.	1048.	1048.	1048.	1048.	1048.
	Site factor = 2.				
300.	229.	229.	229.	229.	229.
400.	289.	289.	289.	289.	289.
500.	346.	346.	346.	346.	346.
600.	398.	398.	398.	398.	398.
700.	448.	448.	448.	448.	448.
800.	495.	495.	495.	495.	495.
900.	540.	540.	540.	540.	540.
1000.	583.	583.	583.	583.	583.
1200.	664.	664.	664.	664.	664.
1400.	739.	739.	739.	739.	739.
	Site factor = 4.				
300.	164.	164.	164.	164.	164.
400.	199.	199.	199.	199.	199.
500.	230.	230.	230.	230.	230.
600.	258.	258.	258.	258.	258.
700.	283.	283.	283.	283.	283.
800.	307.	307.	307.	307.	307.
900.	328.	328.	328.	328.	328.
1000.	348.	348.	348.	348.	348.
1200.	385.	385.	385.	385.	385.
1400.	417.	417.	417.	417.	417.

as M increased. Twenty increments appeared sufficient for this simulation procedure. Trials of different number of increments showed that at different ages, site indexes, and number of tree estimates of B and Y rapidly converged on stable values as M increased. Twenty increments appeared sufficient for this simulation procedure.

For ages 10, total basal area and average diameter of the planted stands are also shown in tables 5.5 and 5.6.

Effect of site preparation

The study by Lenhart and Clutter (1970) was made in successful plantations in northern Georgia. From results of a number of other studies it appears that the survival for all conditions would have a wider range than in the stands they measured. From a variety of sources (Wakeley, 1954; Wahlenberg, 1960; Jones and Thacker, 1965), a number of factors appeared to influence survival rates. Among them are quality of planting stock, soil texture, degree of site preparation, and time of planting. Though some information is available to suggest the economic tradeoffs between these factors, this study assumes the survival rates found by Lenhart and Clutter, but lowered for the effect of inadequate site preparation on cutover sites as in natural regeneration. For each Sf point, survival was lowered .3 probits. The conditions and mean survival expected are:

Table 5.5--Basal area of trees in loblolly pine plantations at age 10, by probability of regeneration and site index.

Seedlings	Site index				
	60.	70.	80.	90.	100.
(Number)	(Basal area in square feet per acre)				
	Site factor = 0.				
300.	51.2	59.2	68.4	78.9	90.8
400.	54.2	63.7	74.7	87.4	101.8
500.	56.6	67.6	80.3	94.9	111.6
600.	58.7	70.9	85.1	101.6	120.4
700.	60.5	73.9	89.5	107.6	128.4
800.	62.0	76.5	93.4	113.1	135.8
900.	63.3	78.8	97.0	118.2	142.7
1000.	64.5	80.9	100.3	123.0	149.2
1200.	66.4	84.6	106.2	131.5	160.9
1400.	67.9	87.8	111.3	139.0	171.3
	Site factor = 2.				
300.	49.4	56.5	64.7	74.1	84.6
400.	51.9	60.2	69.8	80.8	93.2
500.	53.9	63.3	74.2	86.6	100.8
600.	55.6	66.0	78.0	91.7	107.5
700.	57.1	68.3	81.3	96.3	113.5
800.	58.4	70.4	84.3	100.5	118.9
900.	59.5	72.2	87.1	104.2	123.9
1000.	60.5	73.9	89.6	107.7	128.6
1200.	62.2	76.8	94.0	113.9	136.9
1400.	63.6	79.3	97.8	119.4	144.2
	Site factor = 4.				
300.	46.4	52.2	58.7	66.2	74.5
400.	48.1	54.6	62.1	70.5	80.1
500.	49.4	56.6	64.9	74.2	84.8
600.	50.6	58.4	67.2	77.4	88.8
700.	51.6	59.9	69.3	80.2	92.4
800.	52.5	61.2	71.2	82.6	95.6
900.	53.3	62.4	72.9	84.9	98.5
1000.	54.0	63.4	74.4	86.9	101.1
1200.	55.2	65.3	77.0	90.4	105.8
1400.	56.2	66.9	79.2	93.5	109.7

Table 5.6--Average diameter of trees in loblolly pine plantations at age 10, by probability of regeneration and site index.

Seedlings	Site index				
	60.	70.	80.	90.	100.
(Number)	(Diameter in inches)				
	Site factor = 0.				
300.	5.9	6.3	6.8	7.3	7.8
400.	5.3	5.7	6.2	6.7	7.3
500.	4.9	5.4	5.8	6.3	6.9
600.	4.6	5.1	5.5	6.1	6.6
700.	4.4	4.8	5.3	5.8	6.4
800.	4.2	4.6	5.1	5.6	6.2
900.	4.0	4.5	5.0	5.5	6.0
1000.	3.9	4.3	4.8	5.3	5.9
1200.	3.6	4.1	4.6	5.1	5.7
1400.	3.4	3.9	4.4	4.9	5.5
	Site factor = 2.				
300.	6.3	6.7	7.2	7.7	8.2
400.	5.7	6.2	6.7	7.2	7.7
500.	5.3	5.8	6.3	6.8	7.3
600.	5.1	5.5	6.0	6.5	7.0
700.	4.8	5.3	5.8	6.3	6.8
800.	4.6	5.1	5.6	6.1	6.6
900.	4.5	5.0	5.4	5.9	6.5
1000.	4.4	4.8	5.3	5.8	6.4
1200.	4.1	4.6	5.1	5.6	6.1
1400.	4.0	4.4	4.9	5.4	6.0
	Site factor = 4.				
300.	7.2	7.6	8.1	8.6	9.1
400.	6.7	7.1	7.6	8.1	8.6
500.	6.3	6.7	7.2	7.7	8.2
600.	6.0	6.4	6.9	7.4	7.9
700.	5.8	6.2	6.7	7.2	7.7
800.	5.6	6.0	6.5	7.0	7.6
900.	5.5	5.9	6.4	6.9	7.4
1000.	5.3	5.8	6.3	6.8	7.3
1200.	5.1	5.6	6.1	6.6	7.1
1400.	5.0	5.4	5.9	6.4	6.9

Seedbed condition	Factor (Sf)	Survival
Old field	0	84
Cutover or converted		
Intensive site preparation	0	84
Light site preparation	2	66
No site preparation	4	43

Other important factors in plantation survival are insects and diseases, expecially pales weevils and fusiform rust. These will be discussed in Chapter 8. The problems of assuring survial through site preparation in the particularly difficult sand hills areas covered with oaks are discussed in detail by Burns and Hebb (1972).

Use of regeneration estimation procedures

In simulating rotations estimates of stand establishment will be made as follows:

1. Cumulative probability of regeneration (E) will either be specified or determined by random number generator.

2. Site preparation factor (Sf) is determined from cutover, old-field, or converted land classification, and whether the site has been prepared.

3. Age adjustment factor (TAGE) is determined from the land condition class, these are:

Class	TAGE (Natural)	TAGE (Planted)
Old field	-1	-0
Cutover or converted	-1	-2

These assume the oldest nautral seedlings will be one year younger than age since previous stand was harvested. Plantations can be started immediately on old fields and converted stands but must wait for next planting season after site preparation or conversion. Such plantations are also penalized 1 year as discussed in plantation establishment.

4. At age 2 or 3 the success of the regeneration would be evident, and corrective action taken at that time to start over or to thin precommercially, if those treatments are considered at the level of management assumed in the problem. In the simulation program, the decision rule is based on probability, site index, and site factor.

5. Estimation of the stand condition at 10 will be made using procedures for either natural or planted stands.

6. Planted stands will be assumed to grow according to the Lenhart and Clutter procedure from age 10 until they are thinned or cut. The equations in the estimating routine are valid until age 30.

7. If planted stands are thinned, the uniqueness of the uniform spacing will be lost and growth will be simulated according to the procedure used for thinned natural stands. Height growth will continue to be estimated by the height growth equation for planted stands.

Comparison of planted and natural stands

The distinction between natural stands and plantation is of central importance. The comparison is also influenced by seedbed conditions at time of establishment, which depends on whether the stands started on old field and cutover sites. This assumes that site index 80 for natural stands (50-year basis) is equivalent to a planted pine site index of 60

(on a 25-year basis). The comparison of stand attributes of these stands are shown in table 5.7.

Variability of stand establishment

For each biological process, the simulator requires estimates of the uncertainty of the process occurring and the range of results. For stand establishment, the fact that it will occur, to one degree or another is certain. But the probability of establishment success must be indicated in respect to two measures--number of trees and basal area.

For natural stands, the probability distributions for both number of trees and basal area developed for the study have been discussed. The two measures of variation are correlated. The probability of natural establishment is generated only once a rotation.

For plantations, the standard errors of the regression equations to predict number of trees and the maximum diameter in the stand are used. These also were assumed to be correlated. The same randomly chosen probability that more trees will survive is used to estimate the extent the maximum tree diameter is smaller than the mean diameter expected. To continue comparable treatment with natural regeneration, the probability of plantation establishment success is also generated only once--when the stand is 10 years old.

Height growth

The second important biological function is growth of dominant and

Table 5.7--Comparison of average expected attributes for natural and planted loblolly pine stands at stand age 10, 600 trees per acre

Seedbed and attribute	Natural	Planted
Site index[1/] (feet)	80.0	60.0
Total height (feet)	24.0	27.0
Excellent seedbed		
Number of trees	564.0	508.0
Basal area (sq. ft.)	42.7	85.1
Average diameter (inches)	3.7	5.5
Fair seedbed		
Number of trees	276.0	398.0
Basal area (sq. ft.)	24.0	78.0
Average diameter (inches)	4.0	6.0
Poor seedbed		
Number of trees	135.0	258.0
Basal area (sq. ft.)	13.5	67.2
Average diameter	4.3	6.9

1/Site index basis for natural stands is 50 years, for planted stands 25 years.

codominant trees in a stand. Height growth in forests is considered a function of site productivity and age (Schumacher, 1939; Coile, 1952). Except at extremes of stocking, height growth of southern pines is not significantly affected by stand density. For this reason, the site productivity of forest land for a particular species is usually rated by total height of trees in the dominant crown canopy at an index age. Most studies have used an index age of 50 years for natural stands of most species in eastern United States, 25 years for planted stands.

The usual form of a height growth equation as developed by Schumacher (1939) is:

$$\log_{10}(H_t) + a + b_1 / T + b_2 * SI + b_3 * SI / T \qquad (5.5)$$

which produces a sigmoid height curve. Since there is no way to measure site productivity except to equate it with relative rate of height growth, one has to regard site productivity and height growth as the same thing.

The height equation takes many variations and the version developed for natural loblolly pine stand by Schumacher and Coile (1960) is:

$$\log_{10}(H) = \log_{10}(SI) - 6.528 * (\frac{1}{T} - \frac{1}{50}) \qquad (5.6)$$

and that for planted loblolly pine stand by Lenhart and Clutter (1971) is:

$$\log_{10}(H) = 1.5469 - 11.406 / T + 10^{(2.9110 / T)} * [.76481 * \log_{10}(SI) - .83419] \qquad (5.7)$$

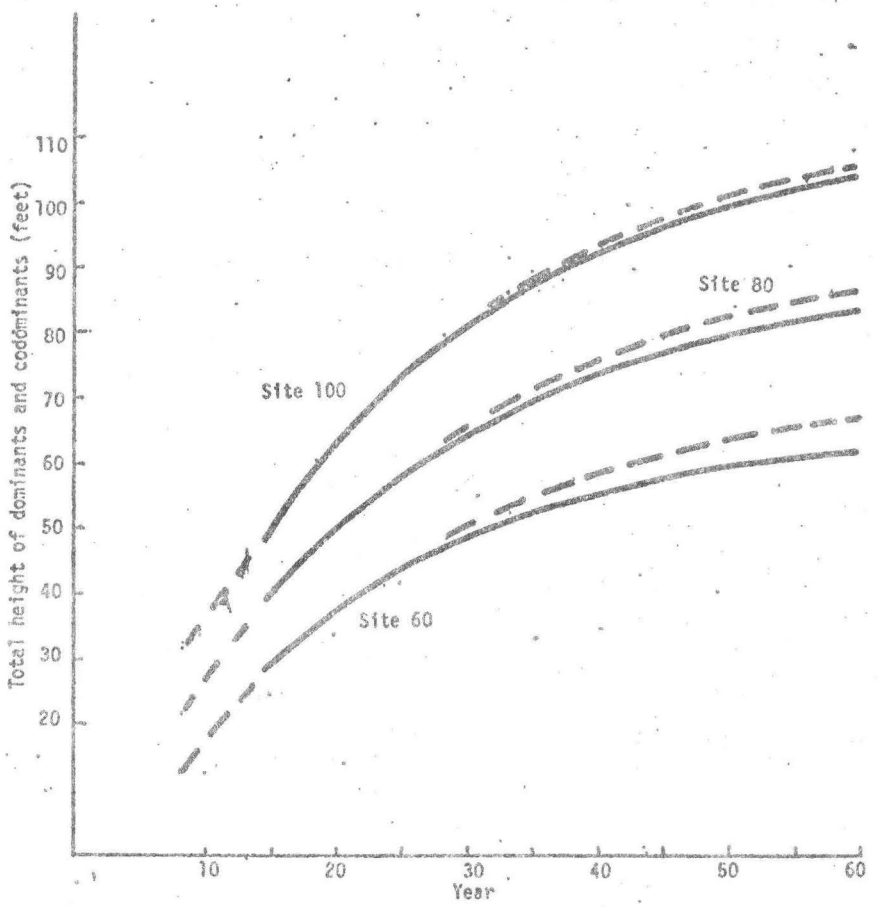
A major aspect of these equations for this study is the comparison of height growth for planted stands with what would be expected if the land were regenerated naturally. For each equation the height at 25 years is roughly 75 percent of the height at 50 years, though the slope of the natural stand seems to be somewhat less than that for planted stands. Thus the site index (25 years) for planted stands was assumed to be .75 of the natural site index used as the principal measure of productivity throughout the study.

This relationship will be improved within a few years as plantations grown on land whose natural site index has been established will be available for measurement.

Figure 5.1 shows the height estimated from these equations for site indexes of 60, 80, and 100 for natural stands and for the roughly equivalent site indexes of 45, 60, and 75 for plantations. The curves for the plantations must be extrapolated for ages beyond 30, since original data do not extend much beyond that age. Similarily, the Schumacher and Coile data are not highly representative of natural stands less than 20 years. Since the method of derivation of these curves assumes an unbiased sample of sites, a higher proportion of old stands on poor sites could have affected the curves. This could have been caused by disproportionate cutting of the more valuable timber on good sites.[2/]

2/Personal communication from Jerome C. Clutter.

Figure 5.1--Comparison of height growth during development of natural stands (solid lines) and plantations (broken lines) assuming site index (age 25) of plantation is equivalent to site index (age 50) of natural stands.



Variability of height growth

Additional data required for this study is the degree of accuracy to which height growth (or site index) can be predicted. The simplest case is predicting the rate of continued growth of an existing stand. The expected value can be obtained from the difference between solutions of the height-age equation for different ages. Few studies of this height growth variation have been made, but informed estimates (Davis, 1965) indicate that height growth has a standard error of about 20 percent of the predicted value over a five-year period. There is no evidence that variations for any given stand are serially correlated. It is assumed they are not.

Estimating height growth for a newly regenerated stand is more difficult. The average site index of a tract must be estmated from either (a) the height growth of the previous stand or (b) from soil characteristics. The accuracy of (a) has not been studied. Conceivably site-index estimates from successive stands on the same land could be correlated. Such a study would take 25 years or more to complete and excellent long-term records from a forest management organization. However, T.S. Coile, formerly the leading soil-site consultant, believed that the accuracy of site productivity determination from previous growth and from soil characteristics was similar (Coile, 1952).

Estimating site-productivity from soil characteristics takes a forester trained in taking soil measurements and applying the estimating equations. The techniques for doing this were developed for the South by Coile (1939). In Coile's major summary (1952), and in subsequent studies (Zahner, 1968; Row, 1960), some 14 individual regression analyses.

of soil-site relations are mentioned. Though these studies used plots of about 1/4 acre, the site index measure probably represents a 10 acre tract. Standard errors of estimate range from 7 to 13 percent with the majority around 10 percent. Though most foresters would have difficulty in determining the soil variables with this accuracy, this study assumes that the standard error for estimating the site index is 10 percent for a 10 acre tract, and declines with size of tract in proportion to the reciprocal of the cube root.

Basal area growth

The most important growth process is diameter growth, or in the aggregate for a stand--basal area growth. Growth studies in forestry have emphasized projection of basal area growth rather than diameter or radial growth. Either measure of growth, either of individual trees or entire stands, is influenced by a large number of factors--age, site productivity, size distribution, and present and past history of stocking.

Almost all available information concerns net growth--live tree basal area of the stand at T_i minus the basal area at T_0. One of the few exceptions is a study of loblolly pine by Schnur (1938). Net basal area growth is gross growth less the basal areas of trees that die during the projection period.

The simulation model incorporates three routines for estimating basal area growth depending on the type of stand. The Schumacher-Coile method (1960) is used for projecting growth of natural unthinned stands, the Lenhart-Clutter (1971) plantation yield study for unthinned plantations, and the Clutter (1963) growth equation for all thinned

pine stands. These will be described in order.

Growth in unthinned natural stands. Schumacher-Coile projection technique employs the "return to normal" assumption. "Normal" stocking at any age is the highest practical occupancy of the site by trees and is set at 100. A stocking index can be computed from basal area, height and age. The formula is:

$$S_t = B_t * [.8409 + .001707 * H_t + 10.62 / T + .1408 * (H_t / T)] \quad (5.8)$$

In a wide variety of forest types many researchers have found that stocking in any stand tend to "return to normal" over time. This occurs both if stocking is greater than 100 because of highly successful regeneration or is less than 100 because of poor establishment or loss from fire, cutting or other disturbances. Understocked stands approach normal stocking because competition among trees is less severe. Reduced competition causes greater tree growth, reduced mortality, and increasingly complete use of the site. Overstocking results in decreased individual tree growth and high mortality. This has been studied in detail by Gevorkiantz (1934), Briegleb (1942), most important by Chaiken (1939)and Wellwood (1943) for southern pines. Schumacher found that this trend toward full stocking can be described by an equation:

$$S_{tb} = 100 * \left(\frac{S_{ta}}{100}\right)^{(T_a / T_b)} \quad (5.9)$$

Where S is stocking and T age, with the subscripts 0 and 1 indicating initial and final time points in a projection period. Extensive plot data fitted this equation without statistically significant discrepancy

after age 20. Growth in thinned plots younger than 20 was larger than the formula indicated, because distribution of trees in thinned stands is substantially more uniform than in natural unthinned stands. From their data an approximate adjustment factor was developed. This factor modified equation 11:

$$S_{tb} = 100 * \left(\frac{S_{ta}}{100}\right)^{[1 - (1 - T_a / T_b * F)]} \qquad (5.10)$$

with F = 1.4 at age 10, 1.2 at age 15, and 1.0 for all later periods. The resulting basal area growth from this equation is shown in table 5.8.

After predicting the change in normality from growth from equation 11a, the basal area of the stand can be computed from a modification of equation 10:

$$B_t = S_t / [.8409 + .001707 * H_t + 10.62 / T + .1408 * (H_t / T)] \qquad (5.11)$$

The standard error of estimate for this relationship was .12 logarithmic units (base 10) or approximately 32 percent for a 1/4 acre plot.

Unthinned planted stands. The Lenhart-Clutter plantation yield estimation procedure described previously for age 10 stands was used to project stand attributes for later periods if the stand was not thinned. The implicit basal area growth rates are shown in table 5.9.

Thinned stands basal area growth equations. For thinned stands it has been found more accurate to estimate growth directly without determining "stocking". Equations to predict basal area growth of stands directly by formula have been developed for a number of species in the South, including loblolly pine (Clutter, 1963; Nelson, Lotti, and

Table 5.8--Basal area growth in unthinned natural loblolly pine stands by stocking at beginning of period, site index and age.

Initial stocking	Site index 60.	70.	80.	90.	100.
(Percent)	(Basal area growth in square feet per acre)				
	Initial age = 10.				
20.	5.27	5.56	5.89	6.25	6.65
40.	5.76	6.11	6.51	6.96	7.46
60.	5.51	5.90	6.33	6.82	7.38
80.	4.90	5.30	5.75	6.26	6.84
100.	4.05	4.45	4.91	5.43	6.02
120.	3.04	3.43	3.89	4.40	5.00
	Initial age = 20.				
20.	2.41	2.57	2.76	2.98	3.24
40.	2.90	3.11	3.36	3.64	3.98
60.	2.87	3.10	3.37	3.68	4.05
80.	2.54	2.77	3.04	3.35	3.73
100.	2.01	2.22	2.47	2.77	3.14
120.	1.32	1.50	1.73	2.00	2.34
	Initial age = 30.				
20.	1.44	1.53	1.63	1.76	1.90
40.	1.74	1.86	1.99	2.14	2.31
60.	1.70	1.82	1.95	2.09	2.27
80.	1.45	1.55	1.66	1.79	1.94
100.	1.04	1.11	1.20	1.30	1.42
120.	0.51	0.56	0.61	0.67	0.74
	Initial age = 40.				
20.	1.10	1.17	1.24	1.32	1.42
40.	1.31	1.39	1.47	1.56	1.67
60.	1.24	1.30	1.37	1.45	1.54
80.	0.98	1.02	1.07	1.12	1.18
100.	0.59	0.61	0.62	0.64	0.65
120.	0.11	0.09	0.07	0.03	-0.01
	Initial age = 50.				
20.	0.89	0.94	0.99	1.05	1.12
40.	1.05	1.10	1.16	1.22	1.29
60.	0.96	1.00	1.05	1.09	1.14
80.	0.72	0.74	0.76	0.78	0.80
100.	0.37	0.36	0.35	0.33	0.31
120.	-0.07	-0.11	-0.16	-0.22	-0.29

Table 5-9--Basal area growth in unthinned loblolly pine plantations by stocking at beginning of period, site index and age.

Initial stocking	Site index 60.	70.	80.	90.	100.
(percent)	(Basal area growth in Square feet per acre)				
	Initial age = 10.				
80.	6.50	7.27	8.34	9.55	10.95
85.	6.51	7.33	8.42	9.67	11.10
90.	6.38	7.41	8.53	9.82	11.29
95.	6.09	7.48	8.62	9.93	11.42
100.	5.70	7.53	8.69	10.00	11.49
	Initial age = 20.				
80.	3.00	4.22	4.84	5.55	6.35
85.	2.75	4.22	4.84	5.55	6.35
90.	2.54	4.23	4.84	5.53	6.32
95.	2.15	4.22	4.81	5.48	6.26
100.	1.72	4.20	4.77	5.42	6.16
	Initial age = 30.				
80.	0.88	2.92	3.34	3.81	4.37
85.	1.39	2.91	3.32	3.79	4.33
90.	1.15	2.89	3.28	3.73	4.25
95.	0.77	2.86	3.23	3.65	4.15
100.	0.38	2.82	3.16	3.56	4.02
	Initial age = 40.				
80.	-0.04	2.22	2.53	2.88	3.29
85.	0.77	2.20	2.50	2.84	3.25
90.	0.55	2.18	2.46	2.78	3.16
95.	0.21	2.14	2.40	2.69	3.05
100.	-0.17	2.10	2.33	2.59	2.91
	Initial age = 50.				
80.	-0.47	1.79	2.03	2.30	2.63
85.	0.43	1.77	2.00	2.27	2.58
90.	0.23	1.74	1.95	2.19	2.48
95.	-0.11	1.71	1.90	2.11	2.38
100.	-0.44	1.67	1.83	2.02	2.25

Brender, 1961). The source of information for both of these studies is a series of growth plots installed by the Southeastern Forest and Range Experiment Station in the 1950's. The more comprehensive analysis of Clutter of this stand density study developed a predicting equation for future basal area:

$$\log_{10}(B_{tb}) = (1.9983 + .005905 * SI) * [1 - (T_a / T_b) - \log_{10}(B_{ta}) * (T_a / T_b)] \quad (5.12)$$

This equation gives slightly different basal area growth table 5.10, than the Schumacher and Coile relationships. Since the procedure is based on an actual sample of thinned plots, it was believed preferable for estimating growth of thinned natural and planted stands.

The standard error of estimate was .77 square feet of basal area per year, or 30.4 percent of the mean annual growth of 2.53 square feet.

Variability of basal area growth estimates

For each of the three methods of estimating basal area growth, measures of the relative variability are available from standard errors of the regression equations. Part of the variability is associated with individual conditions in stands or parts of stands. Much of the growth variation can be associated with yearly differences of rainfall and temperature over a wide area (Coile, 1936). Refinement to incorporate annual variation caused by these causes of climatic variation would not improve the predictability of the model.

As the size of tract increases, however, the error for the entire tract declines. Statistical theory suggests and Forest Survey evidence

Table 5-10--Basal area growth for thinned loblolly pine natural stands by stocking at beginning of period, site index and age.

Initial stocking	Site index 60.	70.	80.	90.	100.
(Percent)	(Basal area growth in square feet per acre)				
	Initial age = 10.				
20.	4.03	4.40	4.79	5.21	5.67
40.	5.38	5.93	6.52	7.16	7.85
60.	6.11	6.80	7.55	8.35	9.22
80.	6.50	7.31	8.18	9.13	10.15
100.	6.66	7.57	8.55	9.62	10.78
120.	6.65	7.64	8.73	9.90	11.18
	Initial age = 20.				
20.	2.45	2.70	2.97	3.28	3.62
40.	3.26	3.64	4.05	4.51	5.03
60.	3.61	4.08	4.60	5.17	5.81
80.	3.69	4.22	4.82	5.48	6.21
100.	3.57	4.16	4.82	5.55	6.35
120.	3.30	3.94	4.65	5.43	6.30
	Initial age = 30.				
20.	1.76	1.94	2.15	2.38	2.64
40.	2.33	2.61	2.92	3.27	3.66
60.	2.54	2.88	3.27	3.69	4.17
80.	2.52	2.91	3.35	3.83	4.38
100.	2.33	2.77	3.25	3.78	4.37
120.	2.03	2.49	3.00	3.56	4.18
	Initial age = 40.				
20.	1.37	1.51	1.67	1.85	2.05
40.	1.81	2.03	2.27	2.54	2.84
60.	1.95	2.22	2.52	2.85	3.23
80.	1.90	2.21	2.55	2.93	3.36
100.	1.71	2.05	2.43	2.84	3.31
120.	1.43	1.79	2.19	2.63	3.11
	Initial age = 50.				
20.	1.12	1.23	1.36	1.50	1.66
40.	1.48	1.65	1.85	2.07	2.31
60.	1.58	1.80	2.05	2.32	2.62
80.	1.52	1.78	2.06	2.37	2.72
100.	1.35	1.63	1.94	2.28	2.66
120.	1.09	1.39	1.72	2.08	2.49

substantiates that the error of estimate declines in proportion to the square root of area. The simulator follows this assumption.

Tree mortality

The final "growth" process that needs to be considered is mortality. In well managed stands tree mortality is a minor factor since competition among trees is not so intense that trees die from overcrowding. In normally stocked and overstocked stands mortality is often a major factor.

Two aspects of mortality need consideration. First is loss of basal area. Expected basal area losses have already been taking into account, since basal area growth estimated from both the Schumacher-Coile and Clutter equations are net basal area growth.

Second, numbers of trees need to be adjusted though basal area growth takes into account mortality. In practical terms this adjustment only increases the average size of trees and has little effect on volume. Clutter (1963) ignores the problem in his study, probably because the count of dead trees was small and not recorded in the basic plot measurements. But since average size has a strong influence on unit values, this adjustment must be made in economic analyses of forest management.

Unthinned natural stands

Schumacher and Coile found that the number of trees in a stand of given age height and basal area could be described as:

$$\log_{10}(N_t) = a + b_1 * (1 / T) + b_2 * \log_{10}(H_t) + b_3 * \log_{10}(B_t) \qquad (5.13)$$

Since height is a function of age for a given site index, the number of trees can be computed for each site index, stocking or basal area, and age. Implicit mortality can be computed by projecting stands 5 years and determining the change in number of trees.

In checking the Schumacher-Coile procedure, the proportion of trees expected to die in a five-year period was computed for 700 combinations of initial age, basal area and site. For most of the range of stand descriptors the computed values were reasonable. But for a few understocked stands, the estimates of mortality were slightly negative--an impossible occurrence.

An improved function was developed by setting each negative mortality estimate to .001, and fitting the computed values to transformation of basal area, number of trees, and other variables by a multiple variable probit analysis. The resulting equation was:

$$
\begin{aligned}
M_{tb} = {} & 6.8526 + .02415 * T_a - .01117 * SI + .3268 / T_a \\
& + 8.4260 / B_{ta} - .06498 * B_{ta} / T_a + .04932 * SI / T_a \\
& - .7370 * T_a / B_{ta} - .03815 * B_{ta} / SI - .00803 \\
& * T_a * B_{ta} / 100. + .001800 * B_{ta} * SI / 100. - .7594 \\
& * \log_{10}(T_a * SI) + 4.8161 * \log_{10}(B_{ta} * SI) - 3.5526 \\
& * \log_{10}(T_a * B_{ta} * SI) \qquad (5.14)
\end{aligned}
$$

where M_{tb} is the proportion of trees dying in a five-year period ending at tb.

This formula estimates the mortality experienced in natural stands where competition tends to weaken and slow the growth of smaller trees, which then die. The solution to this equation is shown in table 5.11 for various combinations of average stand diameter, basal area and age.

Thinning stands removes the smaller trees and reduces mortality to low levels. It does not eliminate it, however, as occasional trees die from lightning, insects, disease and other causes. After reviewing the rates, and comparing them to rates experienced in a variety of thinning studies and in plantations, it appeared that mortality in thinned stands was roughly 1/10 that in natural stands. The general relationship to age, diameter, and density seemed to remain valid. The resulting mortality rates for thinned stands are shown in table 5.12.

Since the observations were derived, a variance estimate is inappropriate.

Unthinned plantations

The Lenhart-Clutter plantation yield procedure implicitly estimates mortality, as does the Schumacher-Coile technique. Computation of mortality rates for the ranges of factors used in this study brought out no problems. The effective 5-year mortality rates are shown in table 5.13.

Stand changes from thinning

While thinning is not a growth process, it changes number of trees, average diameter, total basal area, and volume in the stand. It will not effect height of dominant and codominant trees since these are rarely

Table 5-11--5-year mortality in unthinned natural loblolly pine stands, by original stocking, site index, and stand age.

Initial Stocking	Site index 60.	70.	80.	90.	100.
(Percent)	(5-year mortality in percent of original trees				
	Initial age = 10.				
20.	14.93	14.73	14.47	14.17	13.84
40.	28.58	28.32	27.96	27.53	27.04
60.	40.34	40.05	39.63	39.12	38.53
80.	50.52	50.23	49.78	49.20	48.54
100.	59.40	59.13	58.66	58.04	57.32
120.	60.23	60.01	59.58	59.00	58.31
	Initial age = 20.				
20.	3.62	3.60	3.56	3.50	3.44
40.	10.28	10.12	9.90	9.66	9.42
60.	15.72	15.48	15.17	14.82	14.47
80.	19.99	19.72	19.37	18.97	18.56
100.	23.32	23.07	22.71	22.29	21.87
120.	25.00	24.80	24.46	24.07	23.68
	Initial age = 30.				
20.	0.84	0.87	0.89	0.91	0.93
40.	3.98	3.96	3.92	3.87	3.83
60.	7.02	6.95	6.86	6.75	6.66
80.	9.49	9.43	9.31	9.20	9.10
100.	11.45	11.41	11.32	11.22	11.15
120.	12.98	12.99	12.94	12.88	12.86
	Initial age = 40.				
20.	0.17	0.19	0.20	0.22	0.23
40.	1.59	1.60	1.60	1.60	1.61
60.	3.45	3.44	3.42	3.39	3.38
80.	5.19	5.19	5.16	5.14	5.13
100.	6.71	6.73	6.73	6.73	6.75
120.	7.99	8.06	8.10	8.15	8.23
	Initial age = 50.				
20.	0.04	0.05	0.05	0.06	0.07
40.	0.75	0.76	0.77	0.78	0.79
60.	1.98	1.99	1.99	1.98	1.99
80.	3.28	3.30	3.30	3.30	3.31
100.	4.51	4.55	4.57	4.59	4.64
120.	5.59	5.68	5.74	5.81	5.92

Table 5.12--5-year mortality in unthinned loblolly pine plantations, by original stocking, site index, and stand age.

Initial stocking	Site index 60.	70.	80.	90.	100.
(Percent)	(5-year mortality in percent of original trees)				
	Initial age = 10.				
80.	5.78	5.72	5.76	5.78	5.78
85.	6.05	5.76	5.80	5.82	5.81
90.	6.05	5.81	5.86	5.87	5.85
95.	6.01	5.85	5.90	5.91	5.87
100.	5.95	5.89	5.94	5.93	5.87
	Initial age = 20.				
80.	2.59	2.01	2.09	2.15	2.20
85.	2.64	2.05	2.14	2.21	2.25
90.	2.67	2.12	2.22	2.29	2.33
95.	2.71	2.18	2.29	2.36	2.40
100.	2.73	2.24	2.35	2.42	2.46
	Initial age = 30.				
80.	1.54	0.91	0.99	1.06	1.11
85.	1.46	0.94	1.03	1.11	1.17
90.	1.50	1.00	1.09	1.17	1.24
95.	1.55	1.04	1.15	1.23	1.31
100.	1.59	1.09	1.20	1.29	1.37
	Initial age = 40.				
80.	1.08	0.50	0.57	0.63	0.69
85.	0.96	0.53	0.61	0.67	0.74
90.	1.00	0.56	0.65	0.73	0.80
95.	1.05	0.60	0.70	0.78	0.86
100.	1.09	0.64	0.74	0.83	0.92
	Initial age = 50.				
80.	0.85	0.32	0.38	0.44	0.50
85.	0.72	0.34	0.41	0.47	0.53
90.	0.76	0.37	0.45	0.52	0.59
95.	0.81	0.40	0.49	0.57	0.65
100.	0.85	0.43	0.52	0.61	0.70

Table 5.13--5-year mortality in thinned natural loblolly pine stands by original stocking, site index, and stand age.

Initial Stocking	Site Index 60.	70.	80.	90.	100.
(Percent)	(5-year mortality in percent of original trees)				
	Initial age = 10.				
20.	3.92	3.87	3.80	3.72	3.63
40.	4.95	4.91	4.85	4.77	4.69
60.	5.48	5.44	5.38	5.31	5.23
80.	5.78	5.74	5.69	5.63	5.55
100.	5.94	5.91	5.87	5.80	5.73
120.	6.02	6.00	5.96	5.90	5.83
	Initial age = 20.				
20.	0.50	0.50	0.49	0.48	0.47
40.	1.23	1.21	1.19	1.16	1.13
60.	1.74	1.71	1.68	1.64	1.60
80.	2.09	2.06	2.03	1.98	1.94
100.	2.33	2.31	2.27	2.23	2.19
120.	2.50	2.48	2.45	2.41	2.37
	Initial age = 30.				
20.	0.08	0.09	0.09	0.09	0.09
40.	0.40	0.40	0.39	0.39	0.38
60.	0.70	0.70	0.69	0.68	0.67
80.	0.95	0.94	0.93	0.92	0.91
100.	1.15	1.14	1.13	1.12	1.11
120.	1.30	1.30	1.29	1.29	1.29
	Initial age = 40.				
20.	0.02	0.02	0.02	0.02	0.02
40.	0.16	0.16	0.16	0.16	0.16
60.	0.34	0.34	0.34	0.34	0.34
80.	0.52	0.52	0.52	0.51	0.51
100.	0.67	0.67	0.67	0.67	0.68
120.	0.80	0.81	0.81	0.81	0.82
	Initial age = 50.				
20.	0.00	0.00	0.01	0.01	0.01
40.	0.07	0.08	0.08	0.08	0.08
60.	0.20	0.20	0.20	0.20	0.20
80.	0.33	0.33	0.33	0.33	0.33
100.	0.45	0.45	0.46	0.46	0.46
120.	0.56	0.57	0.57	0.58	0.59

cut when stands are thinned. There are several types of thinning practiced in southern pine forests.[3/]

Precommercial thinning.

Both natural stands and occasionally plantations are thinned at young ages because regeneration is more successful than anticipated or desired. Since no income is derived such thinnings are called "precommercial." To reduce costs and obtain maximum effect, precommercial thinning should be done very early--at age 2-3 years (Grano, 1971). Precommercial thinning in natural stands is accomplished by running a tractor with disk or chopper through the stands in alternating strips or checkerboard fashion, leaving 500 to 800 small patches with one to a few trees. Generally only one tree in a patch will become dominant and crowd out the others. The program simulates this treatment by assuming the stand has only 700 trees successfully established at age 10.

Precommercial thinning in plantations is generally done manually with a brush hook or similar tool. The treatment is necessary only if the stand was planted densely, expecting a high infection of cronartium rust. These plantations were simulated as if the desired stocking had been planted originally.

Commercial thinning

There are also several types of commercial thinning. The simplest

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3/The method of thinning and the results expected have a rich literature. A summary is included in Wahlenberg (1960).

is row or strip thinning of plantations. All trees in every second, third, or fourth row in a plantation are cut and the rest left. With such thinning the reduction in number of trees, basal area, and volume is proportional to the fraction of rows thinned. Average diameter remains the same. TIMSIM is programmed to simulate row thinning, though the treatment is not used in this study.

The usual type of thinning in older stands is "thinning from below" --cutting sufficient smaller, weaker trees to reduce the basal area to the desired basal area standard. The tree marker also marks other poor quality, limby trees and thin trees in dense clumps. Average diameter of thinned trees is less than the average diameter of trees left.

Myers (1971) has found that the average diameter of trees remaining (D_t^*) has a definite relationship to average diameter before thinning (D) and proportion cut (P). If less than half the basal area is cut, the remaining diameter is:

$$D_t^* = .7336 + 1.0201 * D_t - 1.107 * (Pr - .5) + 1.40 * (Pr - .5)^2 \quad (5.15)$$

If more than half is cut, the remaining diameter is:

$$\log_{10}(D_t^*) = .49401 + .71890 * \log_{10}(D_t) + .2250 * \log_{10}(Pr) + .1262 * \log_{10}(D_t) * \log_{10}(Pr) \quad (5.16)$$

Myers included these equations in his simulator of yields of ponderosa pine. The same relationships were applied to a number of thinning situations for southern pine and found to be reasonably applicable. The simulator for the present study contains a rewritten and more efficient computation routine.

Several aspects, however, were changed. The equations assume a diameter distribution typical for natural stands of ponderosa pine. Those for southern pine plantations and thinned stands are quite different. A factor THINF, serves to adjust the effect for this diameter. If $\underline{D}_t^*$ is the diameter of trees left computed from equations (5.15) or (5.16), the adjusted estimate $\underline{D}_t^*x$ is:

$$D_{tx}^* = D_t^* * THINF \qquad (5.17)$$

The ratios between original and thinned component diameters for various preparation of basal area cut and for several values of THINF are shown in table 5.14.

The THINF that appears most appropriate for previously unthinned natural stands is 1.0, that for previously thinned natural stands is .7, and for thinned and unthinned plantations .5.

Special provisions are required to estimate the volume of the thinned and unthinned portions of the stand accurately. The height of components of the stand other than the large dominant trees was that developed by Lenhart and Clutter (1971).

$$\log_{10}(H_t^*) = \log_{10}(H_t) + .02514 + (1 / D_t^* - 1 / Dmax_t) * [-2.7754 + 9.7580 / T + .4433 * \log_{10}(N_t)] \qquad (5.18)$$

where $\underline{H}_t^*$ is the height of a stand component. This was used to estimate the average height of the thinned trees.

From the diameter, height, and number of trees, volume per tree was computed. Total volumes of cut and leave components must usually be slightly adjusted so that their sum equals the original volume of the stand.

Table 5.14--Ratios of average diameter of remaining trees to original stand for various thinning diameter factors

PROPOR. STAND	THINNING DIAMETER FACTOR 1.0	0.9	0.8	0.7	0.6	0.5
CUT	(DIAMETER RATIO)					
	AGE = 15.					
0.1	1.09	1.08	1.07	1.06	1.06	1.05
0.2	1.13	1.13	1.12	1.11	1.11	1.10
0.3	1.16	1.15	1.15	1.15	1.14	1.14
0.4	1.18	1.18	1.17	1.16	1.16	1.16
0.5	1.22	1.22	1.21	1.20	1.19	1.19
0.6	1.28	1.27	1.26	1.25	1.24	1.23
0.7	1.35	1.33	1.32	1.31	1.30	1.29
	AGE = 20.					
0.1	1.06	1.05	1.05	1.05	1.04	1.04
0.2	1.09	1.09	1.09	1.08	1.08	1.08
0.3	1.12	1.11	1.11	1.11	1.10	1.10
0.4	1.15	1.14	1.14	1.13	1.12	1.12
0.5	1.18	1.18	1.17	1.17	1.16	1.16
0.6	1.22	1.22	1.21	1.20	1.20	1.19
0.7	1.28	1.27	1.26	1.25	1.25	1.24
	AGE = 30.					
0.1	1.04	1.04	1.04	1.04	1.04	1.03
0.2	1.07	1.07	1.06	1.06	1.06	1.06
0.3	1.09	1.09	1.08	1.08	1.08	1.08
0.4	1.12	1.10	1.10	1.10	1.09	1.09
0.5	1.15	1.14	1.14	1.13	1.13	1.13
0.6	1.18	1.17	1.17	1.16	1.16	1.16
0.7	1.22	1.22	1.21	1.21	1.20	1.20
	AGE = 40.					
0.1	1.04	1.04	1.04	1.03	1.03	1.03
0.2	1.06	1.06	1.06	1.06	1.05	1.05
0.3	1.08	1.07	1.07	1.07	1.07	1.07
0.4	1.09	1.09	1.09	1.08	1.08	1.08
0.5	1.13	1.13	1.12	1.12	1.12	1.11
0.6	1.16	1.15	1.15	1.15	1.14	1.14
0.7	1.20	1.19	1.19	1.18	1.18	1.18

Total and utilized volume

The final phases of the physical simulation is estimation of the units of yield. Simulated number, diameters, and heights of trees are used to estimate total and then useable volume of timber yields. Though supposedly one of the more straightforward portions of the simulating system, formulas for determination of volume caused substantial problems.

Individual tree and volume

The volume of a tree is a function primarily of its diameter and total height. If trees were perfect cones the volume per tree would be:

$$Y_t/N_t = \frac{1}{3} * k * D_t^2 * H_t$$

or: $$Y_t/N_t = .001818 * D_t^2 * H_t \quad (5.19)$$

where Y_t/N_t is volume in cubic feet per tree, and $k = \pi / (4 * 12 * 12)$. But diameter is generally measured at breast height outside bark, and trees are tapered elipsoids rather than cones (Row and Guttenberg, 1965). Thus the constants of statistically fitted volume equations differ according to the degree of taper. For example, the equation Bailey and Clutter (1970) developed for plantation yields was:

$$Y_t/N_t = .00914 + .0009281 * D_t * D_t * H_t \quad (5.20)$$

A very similar equation resulted from an independent study by Smalley and Bower (1971):

$$Y_t/N_t = .00709 + .0020695 * D_t * D_t * H_t \quad (5.21)$$

A different equation form was used in the Schumacher and Coile yield study. It was derived from MacKinney and Chaiken (1939). Its

formula was:

$$Y_t/N_t = .001511 * D_t^{1.9557} * H_t^{1.0971} \qquad (5.22)$$

Computed values for the MacKinney and Chaiken natural stand equation are 2-3 percent lower than the plantation volume equation of Smalley and Bower, but 3-8 percent larger than the Bailey and Clutter volumes. For consistency, the study adopted volume relationships based on the MacKinney and Chaiken equation for all stands. Volumes estimated from the equation are shown in table 5.15, for selected diameters and heights. The ratio between volume and basal area is nearly constant for each height.

Aggregate stand volume

In the aggregate stand simulation system used, individual trees are not identified but the entire stand is characterized by average tree diameter, total height of dominant and codominant trees, and number of trees. Applying an equation for individual tree volume to the average tree does not quite give an accurate estimate of average tree volume.

Schumacher and Coile developed a separate equation for the average volume of a tree in a stand described by average diameter and total stand height. They first developed a modified equation for individual tree diameters by stand height instead of tree height. They applied this to the distribution of diameters in the plots they studied. By regression they determined an equation for average tree volume by stand diameter and total height. The resulting equation is:

$$Y_t/N_t = .000247 * D_t^{1.3321} * H_t^{1.7411} \qquad (5.23)$$

Table 5.15--Tree volume tables for loblolly pine used as basis for stand volume tables.

Diameter	Total tree height					
	40.	50.	60.	70.	80.	90.
(Inches)	(Gross volume per tree in cubic feet)					
5.	2.01	2.57	3.14	3.72	4.30	4.90
6.	2.87	3.67	4.48	5.31	6.15	7.00
7.	3.89	4.96	6.06	7.18	8.31	9.46
8.	5.05	6.44	7.87	9.32	10.79	12.28
9.	6.35	8.11	9.91	11.74	13.59	15.46
10.	7.81	9.97	12.18	14.42	16.70	19.00
11.	9.41	12.01	14.67	17.38	20.12	22.90
12.	11.15	14.24	17.40	20.60	23.85	27.14
13.	13.04	16.66	20.34	24.09	27.89	31.74
14.	15.07	19.25	23.52	27.85	32.24	36.69
15.	17.25	22.04	26.91	31.87	36.90	41.99
16.	19.57	25.00	30.54	36.16	41.87	47.64
17.	22.03	28.15	34.38	40.71	47.14	53.64
18.	24.64	31.48	38.45	45.53	52.71	59.98
19.	27.39	34.99	42.73	50.61	58.59	66.67
20.	30.28	38.68	47.24	55.95	64.77	73.71
	(Cubic feet per square foot basal area)					
5.	14.76	18.85	23.03	27.27	31.57	35.93
6.	14.64	18.70	22.84	27.05	31.32	35.64
7.	14.54	18.57	22.69	26.87	31.10	35.40
8.	14.45	18.46	22.55	26.71	30.92	35.19
9.	14.38	18.37	22.43	26.57	30.76	35.00
10.	14.31	18.28	22.33	26.44	30.62	34.84
11.	14.25	18.20	22.24	26.33	30.49	34.69
12.	14.20	18.13	22.15	26.23	30.37	34.56
13.	14.15	18.07	22.07	26.14	30.26	34.44
14.	14.10	18.01	22.00	26.05	30.16	34.32
15.	14.06	17.96	21.93	25.97	30.07	34.22
16.	14.02	17.91	21.87	25.90	29.99	34.12
17.	13.98	17.86	21.81	25.83	29.91	34.03
18.	13.94	17.81	21.76	25.76	29.83	33.94
19.	13.91	17.77	21.70	25.70	29.76	33.86
20.	13.88	17.73	21.65	25.64	29.69	33.79

Calculated solutions for various diameters and heights are shown in table 5.16. The volume per square foot basal area declines as the diameters increases. This is because natural stands contain many smaller diameter trees substantially shorter than the height of the dominant stand.

Lenhart and Clutter developed stand volumes by a different method. Using the beta function procedure they simulate the distribution of diameters according to number of trees, age and height. Height for each increment of diameter are estimated separately, allowing volume to be computed using an individual tree volume equation and summed. Thus they do not need a stand volume equation such as Schumacher and Coile developed.

The implicit relationship of stand volume to average variables is quite different from that resulting from Schumacher and Coile's work. This was developed in this study by simulating the estimated average diameter, dominant stand height, and total volume for plantations from 200 to 1200 trees and from age 10 to 30. The resulting average volume per tree formed the independent variable for a regression analaysis using the same form as Schumacher and Coile's. The resulting equation was:

$$Y_t/N_t = .001423 * D_t^{2.1045} * H_t^{1.0262} \qquad (5.24)$$

Solutions per tree and per square foot basal area are shown in table 5.17. The decline in volume per square foot basal area is much less than in Schumacher and Coile's work. The difference is due to more uniform diameter and heights in plantations.

Table 5.16--Stand volume tables for loblolly pine for unthinned natural stands.

Diameter	Total height of stand in feet					
	30.	40.	50.	60.	70.	80.
(Inches)	(Net volume per tree in cubic feet)					
5.	0.77	1.30	1.93	2.65	3.44	4.30
6.	1.23	1.99	2.88	3.88	4.97	6.15
7.	1.75	2.78	3.96	5.27	6.70	8.24
8.	2.34	3.66	5.16	6.82	8.63	10.56
9.	2.99	4.63	6.48	8.53	10.75	13.11
10.	3.69	5.68	7.92	10.39	13.05	15.88
11.	4.46	6.82	9.48	12.39	15.53	18.87
12.	5.28	8.05	11.15	14.54	18.18	22.06
13.	6.16	9.35	12.92	16.82	21.01	25.46
14.	7.09	10.73	14.80	19.24	24.00	29.05
15.	8.07	12.19	16.78	21.78	27.15	32.84
16.	9.10	13.72	18.87	24.46	30.45	36.81
17.	10.18	15.33	21.04	27.26	33.91	40.97
18.	11.31	17.00	23.32	30.18	37.52	45.30
19.	12.48	18.74	25.69	33.22	41.28	49.82
20.	13.70	20.55	28.14	36.38	45.18	54.50
	(Cubic feet per square foot basal area)					
5.	5.64	9.54	14.17	19.44	25.25	31.54
6.	6.26	10.15	14.68	19.76	25.32	31.31
7.	6.56	10.40	14.81	19.73	25.08	30.82
8.	6.70	10.48	14.78	19.55	24.72	30.25
9.	6.76	10.47	14.68	19.31	24.33	29.68
10.	6.77	10.42	14.53	19.05	23.92	29.12
11.	6.76	10.34	14.37	18.78	23.53	28.59
12.	6.73	10.25	14.19	18.51	23.15	28.09
13.	6.68	10.15	14.02	18.25	22.79	27.62
14.	6.63	10.04	13.85	18.00	22.45	27.18
15.	6.58	9.94	13.68	17.75	22.12	26.76
16.	6.52	9.83	13.51	17.52	21.81	26.36
17.	6.46	9.72	13.35	17.29	21.52	25.99
18.	6.40	9.62	13.20	17.08	21.23	25.64
19.	6.34	9.52	13.05	16.87	20.97	25.30
20.	6.28	9.42	12.90	16.67	20.71	24.98

Table 5.17--Stand volume tables for unthinned pine plantations.

Diameter	Total height of stand in feet					
	30.	40.	50.	60.	70.	80.
(Inches)	(Net volume per tree in cubic feet)					
5.	0.80	1.22	1.68	2.16	2.65	3.16
6.	1.38	2.01	2.69	3.39	4.11	4.85
7.	2.08	2.98	3.92	4.89	5.89	6.90
8.	2.93	4.13	5.39	6.67	7.99	9.32
9.	3.92	5.48	7.09	8.74	10.42	12.12
10.	5.05	7.01	9.03	11.09	13.18	15.30
11.	6.33	8.74	11.21	13.73	16.28	18.86
12.	7.76	10.66	13.64	16.66	19.73	22.82
13.	9.33	12.78	16.31	19.89	23.51	27.17
14.	11.06	15.11	19.23	23.42	27.65	31.91
15.	12.93	17.63	22.41	27.25	32.13	37.06
16.	14.96	20.35	25.83	31.37	36.97	42.60
17.	17.13	23.27	29.50	35.80	42.16	48.55
18.	19.46	26.40	33.43	40.54	47.70	54.91
19.	21.94	29.73	37.61	45.57	53.60	61.67
20.	24.57	33.26	42.05	50.92	59.85	68.84
	(Cubic feet per square foot basal area)					
5.	5.88	8.98	12.31	15.82	19.44	23.16
6.	7.01	10.25	13.69	17.27	20.94	24.69
7.	7.80	11.16	14.68	18.31	22.03	25.81
8.	8.39	11.84	15.43	19.12	22.88	26.70
9.	8.87	12.40	16.04	19.78	23.58	27.43
10.	9.26	12.85	16.55	20.33	24.17	28.04
11.	9.59	13.24	16.99	20.80	24.67	28.58
12.	9.88	13.58	17.36	21.22	25.12	29.05
13.	10.12	13.87	17.70	21.58	25.51	29.47
14.	10.34	14.13	17.99	21.91	25.87	29.85
15.	10.54	14.36	18.26	22.20	26.19	30.20
16.	10.71	14.57	18.50	22.47	26.48	30.51
17.	10.87	14.77	18.72	22.72	26.75	30.80
18.	11.01	14.94	18.92	22.94	26.99	31.07
19.	11.14	15.10	19.10	23.15	27.22	31.32
20.	11.26	15.24	19.27	23.34	27.43	31.55

Since there is a valid distinction in volume relationship, it appears advisable to use separate volume equations for natural stands and plantations. But what of thinned stands? Thinning in effect removes the smaller, shorter trees that affect the stand volume equation of Schumacher and Coile. In spacing, diameter and height distribution, a thinned stand resembles a planted stand more than a natural stand. Therefore the equation derived in this study based on plantation simulation was used for all planted stands, the Schumacher-Coile euqation for unthinned natural stands, and a compromise equation midway between for thinned natural stands. The equation for the latter is:

$$Y_t/N_t = .000760 * D_t^{1.7133} * H_t^{1.3636} \qquad (5.25)$$

and its predicted volume are shown in table 5.18.

Utilization factors

Only part of total tree volume can be utilized for products. Portions of the stump and top are usually left in the woods. Utilization proportions are partly dependent on markets and logging methods. Thus utilization was computed separately, permitting modifications corresponding to different practices.

Utilization rates are also dependent on diameter and height. Smaller trees, and short, squat trees have higher proportions of their volume in top and stump than slender, slightly tapered trees.

To determine a utilization function, the unutilized volumes implicit in net volumes tables of MacKinney and Chaikin (1939) were computed for each diameter and height class of individual trees. A regression analysis determined that the logarithm of the proportion of non-utilized

Table 5.18--Stand volume tables for thinned loblolly pine natural stands.

Diameter	Total height of stand in feet					
	30.	40.	50.	60.	70.	80.
(Inches)	(Net volume per tree in cubic feet)					
5.	0.79	1.26	1.80	2.39	3.02	3.69
6.	1.30	2.00	2.78	3.63	4.52	5.46
7.	1.91	2.88	3.94	5.08	6.28	7.54
8.	2.62	3.89	5.27	6.75	8.30	9.92
9.	3.42	5.03	6.78	8.63	10.58	12.60
10.	4.32	6.31	8.46	10.73	13.11	15.59
11.	5.31	7.72	10.31	13.04	15.90	18.86
12.	6.40	9.26	12.33	15.56	18.94	22.44
13.	7.58	10.93	14.52	18.29	22.23	26.30
14.	8.85	12.73	16.87	21.23	25.76	30.45
15.	10.22	14.66	19.39	24.36	29.54	34.88
16.	11.67	16.71	22.07	27.70	33.55	39.60
17.	13.21	18.89	24.92	31.24	37.81	44.60
18.	14.84	21.18	27.92	34.98	42.31	49.87
19.	16.55	23.60	31.08	38.91	47.04	55.43
20.	18.35	26.14	34.40	43.04	52.00	61.25
	(Cubic feet per square foot basal area)					
5.	5.76	9.26	13.21	17.53	22.16	27.03
6.	6.63	10.20	14.18	18.47	23.03	27.80
7.	7.15	10.77	14.74	19.01	23.51	28.21
8.	7.50	11.14	15.10	19.34	23.79	28.42
9.	7.74	11.39	15.34	19.54	23.95	28.53
10.	7.92	11.57	15.51	19.68	24.05	28.58
11.	8.05	11.70	15.62	19.76	24.10	28.59
12.	8.15	11.79	15.70	19.82	24.12	28.57
13.	8.22	11.86	15.75	19.85	24.11	28.53
14.	8.28	11.91	15.78	19.86	24.10	28.48
15.	8.32	11.95	15.80	19.85	24.07	28.43
16.	8.36	11.97	15.81	19.84	24.03	28.36
17.	8.38	11.98	15.81	19.82	23.99	28.29
18.	8.40	11.99	15.80	19.79	23.94	28.22
19.	8.41	11.99	15.79	19.76	23.89	28.15
20.	8.41	11.98	15.77	19.73	23.84	28.08

volume was related to various transformations of volume and height. The resulting equation is:

$$\log_{10}(U) = 4.5623 / D_t - .11501 * D_t - .014256 * H_t + .22934 * \log_{10}(H_t) \quad (5.26)$$

where the utilization rate is 1. - U. The solutions to this equation are presented in table 5.19.

Differences in utilization rate function for different stand conditions probably exist but were thought to be minor.

Accounting for quality

As will be seen in Chapter 6, quality is an important determinant of prices for sawtimber. The variable found most closely related to price bid is percentage of volume in tree grades A and B. These grades are standard tree grades based on yield of lumber by grade when sawed in standard patterns (U.S. Forest Service, 1965).

These grades are associated with moderate rates of growth in relatively well stocked stands. The shading causes the lower branches to die early and drop off allowing a clean straight hole to develop. In addition fast rates of growth produce lumber with too few rings per inch to meet structural standards. Standards for medium dense and dense grades require 4 and 6 rings per inch respectively, or an unusual percentage of summer wood (Row and Guttenberg, 1963).

No known yield table estimates the volumes of timber by a quality classification that could be directly associated with these grades. Ignoring grades both in the price equation and the simulation model was considered, but difficulties developed in appraising timber grown at

Table 5.19--Rate of volume utilization by diameter and height.

Diameter 1	Total height of tree in feet					
1	40.	50.	60.	70.	80.	90.
(Inches)	(Utilization rate in decimals)					
5.	0.660	0.720	0.767	0.805	0.836	0.861
6.	0.740	0.785	0.822	0.851	0.874	0.894
7.	0.792	0.828	0.857	0.881	0.900	0.915
8.	0.829	0.859	0.883	0.902	0.917	0.930
9.	0.857	0.882	0.902	0.918	0.931	0.942
10.	0.879	0.900	0.917	0.930	0.941	0.951
11.	0.896	0.915	0.929	0.941	0.950	0.958
12.	0.911	0.926	0.939	0.949	0.957	0.964
13.	0.923	0.936	0.947	0.956	0.963	0.969
14.	0.933	0.945	0.954	0.961	0.968	0.973
15.	0.941	0.952	0.960	0.966	0.972	0.976
16.	0.949	0.958	0.965	0.971	0.975	0.979
17.	0.955	0.963	0.969	0.974	0.978	0.982
18.	0.961	0.967	0.973	0.977	0.981	0.984
19.	0.965	0.971	0.976	0.980	0.983	0.986
20.	0.969	0.975	0.979	0.982	0.985	0.988

low stocking densities. Unrealistically high values resulted, which biased the results in Chapter 10 toward short rotations. Thus an approximate procedure for estimating percentage of A and B tree grades was needed.

First, the average proportion of grade A and B volume by diameter class in sale data for the price regressions in Chapter 6 served as a guide for what intensive management would produce. If those sales were grown in fully stocked unthinned stands, the earliest any A or B grade trees would occur would be 25 years, and by 65 years nearly all the volume would be A or B trees.

This suggested a quality index (QI) system based upon the number of years a stand had grown at full stocking, each year being one point. The proportion of grades A and B would be:

$P(A + B) = 0.$	if $QI \leq 25$
$P(A + B) = (QI - 25.) / 40$	if $25 < QI \leq 65$
$P(A + B) = 1.0$	if $65 < QI$

For growing conditions less than full stocking, the quality points accrued each year are less than that at full stocking. Below stocking of 30 (for both pine and hardwood) no quality points would accrue, and the maximum would be reached at full stocking. Thus Q, with QI = Q is:

$Q = 0.$	if $S \leq 30$
$Q = (S-30.) / 70.$	if $30 < S \leq 100$
$Q = 1.$	if $100 < S$

Since thinnings generally tend to remove low grade trees and leave better ones, the sum of quality points was increased 10 points for each thinning. This more than compensates for the lower accrual of points because of reduced stocking.

Control of hardwood growth

In the South a major problem is hardwood sprouting from old root-stocks and fresh invasion during regeneration and throughout the life of the stand. Many hardwood species, unlike pine, are tolerant of shade. They establish and survive quite well in partial or total shade. When released by cutting the overhead canopy, they grow rapidly, often crowding out pine regeneration and during later periods. The cutting accelerates the natural ecological succession toward the hardwood forest that would be the climax stage after the pine would be. The stages of ecological succession are described in Oosting (1942), and Coile (1940).

While this study concerns pine timber growing, it required some measure of approximating the impact of unchecked hardwood growth. Since the growth of hardwoods only affects unmanaged stands, however, the procedures incorporated are highly simplified. They would not be suitable for simulation of hardwoods if hardwoods were to be a part of the desired yields.

In computing the increased income obtained from converting upland pine sites, some measure of the value of the hardwood growth was needed. The following yields are a compromise among various sources, particularly Schnur (1937). Other studies, such as Guttenberg and Anderson (1971), give virtually no value to hardwoods.

Age	Pine site class		
	60	80	100
	(Cubic foot yields)		
30	305	790	1725
40	636	1220	2300
50	970	1645	2820
60	1280	2030	3320

Hardwood growth and control procedures

The following are more detailed assumptions incorporated into the model:

1. Hardwoods will invade pine sites, particularly without site preparation. In effect, at 10 years the difference between normal stocking of pine and actual is largely made up by invasion of hardwoods. Arbitrarily the proportion of the pine basal area "gap" filled by hardwoods is 3/4 without site preparation, 1/4 with site preparation.

2. Basal area hardwood growth is the same as that of pine. A projection method incorporating this assumption developed by Schumacher and Coile (1960) is used. In effect the growth of the entire stand is projected assuming it is all pine. Then the actual pine growth and number of trees is the proportion of pine to the total. This procedure thus tends to reduce pine growth and increase mortality because of increased competition.

3. Prescribed burning tends to reduce hardwood basal area. The arbitrary rule of thumb based on limited evidence is that if burned every five years (or earlier) hardwood basal area at the end of the period (HBA), is:

$$HBA_{tb} = HBA_{t_a} * (1. - 10. / T_a) \qquad (5.30)$$

which indicates that as the stand gets older the remaining hardwood trees (presumably bigger) are more difficult to kill.

There are additional reasons for prescribed burning. It reduces the amount of litter on the forest floor or caught on low branches or shrubs. Thus the fuel to sustain uncontrolled wildfire is reduced sharply, and fire hazard is thereby lessened. This is discussed more fully in

Chapter 8. In addition prescribed fire permits easier timber sale marking and logging. It has both favorable and unfavorable effects on wildlife.

4. In plantations on cutover and converted lands, spraying the hardwoods with a herbicide at about age 3 is often needed to assure the planted pines of release (Romancier, 1965). The program assumes that such spraying will reduce hardwoods to levels that have insignificant effects on growth.

Summary

This chapter develops the sources and logic used in assembling biological functions of establishment and growth of stands of various types, and the equations to estimate volume and utilization rate.

The results unfortunately do not completely reconcile the differences in approach used by different researchers. Numerous problems needing further study are noted, but are beyond the scope of this study.

The procedures for simulation adopted represent the best accommodation possible, and emphasize consistency rather than mensurational elegance. Other more detailed approaches are conceptually possible, but the biological functions for them have not been developed.

Chapter 6

PATTERNS AND TRENDS IN TIMBER PRICES

The South is fortunate in having active markets for a variety of timber products. These markets produce a complex and changing price structure for timber. Because of its importance, southern pine is one of the few types of timber whose price structure has been extensively investigated (Guttenberg, 1956; Anderson, 1969).

But few of these studies have explored in detail the relation between price patterns and southern pine timber management decisions. Most economic evaluations of timber growing alternatives have used only one or several levels of uniform flat prices of pulpwood and sawtimber to determine the range of financial returns from a given management alternative. Price differential for size of sale, volume per acre, size or grade of trees have not been assumed. An exception is a study of grade of lumber grade differentials on timber management (Row and Guttenberg, 1962).

Three aspects of timber prices are important for this study of the profitability of timber growing:

1. What is the present pattern of prices for different sizes, quality, and types of timber?

2. What is the variation in prices that an individual owner might expect to receive?

3. How may the pattern of timber prices change in the

future?

All of these problems must be given extensive consideration if expectations of prices in the future are to be realistic. Timber owners in the south have become far more aware of timber prices in recent years and are increasingly aware of patterns and trends.

The southern pine timber market

Demand for timber is derived from that of its final products. Among the major southern pine end uses are new housing and other construction, manufacturing and shipping, and pulp and paper(USDA Forest Service, 1973). Construction consumes most of the solid wood products such as lumber, plywood, and utility poles, for which about half of the timber is cut. The other 50 percent of southern pine timber goes into pulp and paper manufacture. Southern pine's long fibers make it preferred for kraft grades, primarily used for packaging.

In all major uses, the value of the wood raw material is a low proportion of the final end value. Physical raw material requirements for most stages of processing are relatively fixed, and supplies of other intermediate inputs are generally elastic. As could be inferred from the principle of derived demand, demand for southern pine timber is thus relatively price inelastic.

In most regions, supplies of open market timber tend also to be inelastic, because much of the supply is cut by forest industries on their own lands or is sold by government agencies on a fixed schedule. In the South however, a large proportion

of the supply comes from land of individual private owners, making the supply somewhat more elastic than in the U.S. as a whole (Mills, 1973). The result of inelastic demands and supply is the high volatility of both lumber prices and stumpage prices. Stumpage prices are more volatile then lumber prices, as shown by studies of Guttenberg and Row (1961), and Anderson (1969).

Trends in forest product industries in the South have also strongly affected timber price trends during the last 20 years. Demand for timber in large diameter trees comes largely from the lumber and plywood industries. A long historic decline in southern lumber production ended in the 1950's. The decline caused the disappearance of small portable mills and concentration yards. Recovery of the industry in the 1960's was accompanied by replacement and enlargement of most permanent sawmills. After southern pine plywood production was shown technically and economically feasible in the early 1960's, a plywood industry emerged and now produces one quarter of the nation's plywood. Removals of southern pine timber of sawtimber size increased from 2.2 to 2.7 billion cubic feet for 1952 to 1970 (USDA Forest Service, 1973).

The major demand for small-sized southern pine timber is from the pulp and paper industry. Removals of poletimber in the South rose from .9 billion cubic feet in 1953 to 1.3 in 1970, though the expansion of demand was not steady. From the late 1950's and lasting until 1966 most of the increase in wood

consumption by the pulp and paper industry came from expanded use of residues from sawmill, plywood and other industrial plants.

In addition there are strong but localized demands for southern pine timber for use as piling and utility and construction poles. These used about .1 billion cubic feet of southern pine timber. This high-value use increases unit prices of straight, small-taper, middle-sized trees (Williston, 1957). To get the highest revenue from all products, many progressive forest product firms do not buck the timber into log lengths in the woods, but haul the timber tree-length and cut it into the highest-valued combination of logs and bolts at the mill.

Markets for southern pine are not highly organized. Most timber cut on lands of individual owners is sold as stumpage--the right to cut and remove standing timber. Sawtimber is sold by the thousand board feet, pulpwood by cord, and poles by the tree. Each unit has different standards and methods of measure.

Because of infrequent sales, few individual owners are familiar with timber marking, units of measure, quality, and relative value. Consequently a wide variety of sales arrangements are used. For example, timber buyers representing processors frequently scout likely tracts and offer owners some form of lump sum payment for the timber. In recent years, however, land owners in the South increasingly use consulting or state foresters to assist in marking, inventorying, and contacting several buyers to bid on a sale.

In developing price patterns and trends for this study,

it is necessary to adopt several assumptions. These are that the owner will:

1. Expect to sell the timber they grow at prevailing market prices at the time of sale. They will not enter into long-term leases or sales commitments that would influence prices.

2. Cut timber regardless of the phase of the business cycle. Thus he may not realize the higher income that might be obtained by timing sales to occur when lumber demand is strong and, consequently, timber prices high.

3. Expect the same pattern of relative prices for different qualities of timber to persist.

4. Anticipate a price rise to follow historical trends that have occurred in the last 20 years.

The present pattern of prices

Since timber of different size is usually sold by different units, prices of different products cannot be directly compared. Such comparison requires converting prices in merchantable units to values in a common unit. To simplify presentation, this study will express all timber prices in cubic foot units. Though unorthodox, the practice has substantial merit for both market and analytical use.

Several factors cause major differentials in the prices. These factors are:

1. Tree size. Small trees are generally cut into low-valued pulpwood bolts; large trees are cut into generally high-valued sawlogs or veneer logs used for lumber and plywood. Size also

is a major determinant of costs of logging and processing--costs for small trees are much higher than for large trees.

2. Tree grade. Standard log and tree grades for southern pine are based on tree size and relative freedom from visible knots and defects (USDA Forest Service, 1965). Grade in turn is a function of age, and the conditions under which the timber is grown. Knot-free lumber and plywood have much higher valued uses than wood with many knots and other defects. Freedom from knots and defects is important, however, only for trees of sawlog or veneer log size, or trees which would make high quality piling or utility poles. High wood density, which is associated with tall, limb-free and high-grade trees, also increases pulp and paper yields. Grade and other measures of quality are major factors that the forest manager or owner can control in producing timber.

3. Stand density and size of sale. Aside from influence of density on yields and grade, these factors influence the costs of logging. High densities of cut and large sale acreages make for more economical timber harvesting.

4. Location and competition. Because timber cannot be economically hauled more than 50 to 100 miles, distance of the timber sale from mills is important in determining price. Mills without hauling distance to any tract may range from just a few to a score of more. Many of these mills may own adequate timber supplies or have a supply under lease or contract. Therefore numbers of potential bidders and price levels may vary sharply

from locality to locality and from time period to time period. These factors cannot be taken into account directly but increase the variance of expected prices.

5. Knowledge of timber seller. Though undoubtedly important for prices received, this measure cannot be analyzed separately. The present study will assume that timber owners will sell their timber under the direction of a person experienced in the timber market. This would most likely be a consulting forester or a State service forester.

Ways of determining price patterns

Though unavoidable in past studies of some species, use of flat prices is unrealistic in financial analysis of timber growing. The various approaches to determine current price patterns in analyses of timber growing are:

1. Flat prices for sawtimber and for pulpwood. This approach, commonly used in analyzing timber growing investments, ignores all price factors except the obvious differences between sawtimber and pulpwood price levels. Some studies, however, have suggested supplementary use of a subjectively estimated quality-index to modify price. Examples are in Row (1963) and Chappelle and Nelson (1956).

2. Synthetic price patterns based upon the residual value or conversion-return concept (Duerr and Guttenberg, 1968). Public agencies use residual values to appraise timber for sale. This approach has several steps: (a) a mill study determines average processing yields of certain sizes and classes of logs

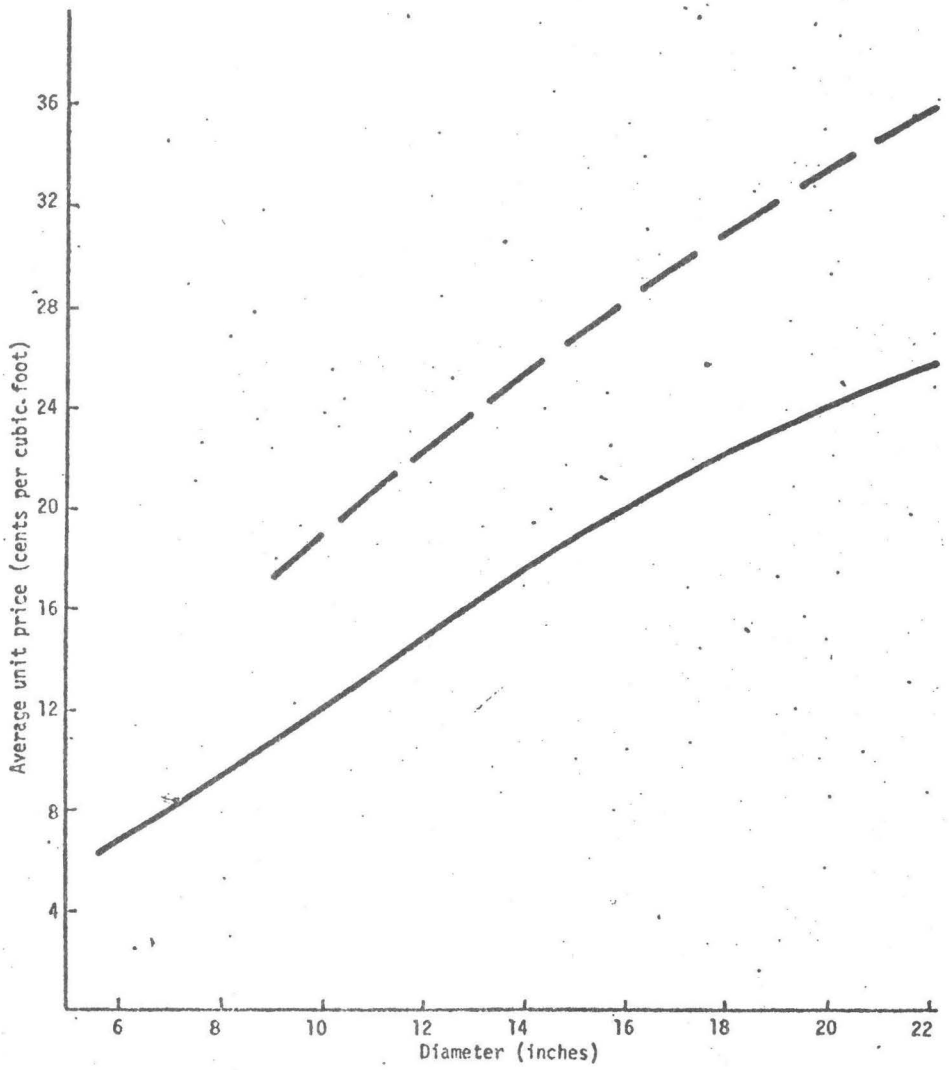
and trees, (b) grade yield proportions from mill studies are valued according to current lumber and plywood prices, (c) values of product yields, including byproducts, are translated to values of logs and then trees by applying physical output or "overrun" factors, to obtain gross conversion value, (d) costs of logging, processing, and distribution, as well as an allowance for profit, are subtracted to obtain net conversion value.

An excellent example is a study by McClay (1969) who used mill studies run by the Southern region of the Forest Service, and prevailing costs and prices for lumber by grade collected by purchasers of Forest Service timber. McClay's study was unusual, however, because he converted the net conversion values for sawtimber and for pulpwood into prices per cubic foot and constructed a smooth curve of average prices by diameter class. This curve of prices for 1967 is shown by the heavy line in figure 6.1. The values adjusted to current increased price levels are shown by the dotted line.

Another analytical method similar in concept but different in approach employs shadow prices from linear programming studies of sawmill and plywood operations. The results of Row, Fasick, and Guttenberg (1965) illustrate the technique.

Shortcomings of the synthetic or conversion surplus price technique are: (a) it is difficult to include tree and stand factors, particularly those influencing cost in the residual value computation or in the classification of trees and logs, (b) it assumes that the price setting mechanism for stumpage

Figure 6.1--The relationship of stumpage prices to average diameter of trees sold. Prices from McClay (1969) are shown in solid line; broken line indicates adjustment to recent lumber price levels used in this study.



prices works perfectly--buyers perceive differences in timber quality and cost in the way that they affect lumber and plywood yields and the perceptions influence their bids for the timber, (c) it neglects the fact that for each size or grade of timber there may be a number of products or methods of cutting or processing. Mills may have quite different use patterns depending on location and market situation. Residual values must assume a representative mill.

3. Econometric equations resulting from regression analyses of prices from public or private timber sales. In studies conducted so far, dependent variables have been unit prices for commercial measures as thousand board feet or cord, and independent variables have been either market, location, or timber quality factors.

The only species group in the United States for which this technique has been extensively tried is southern pine. Three series of studies have been published: The first series used some 747 sales conducted over a 20-year period of private timber conducted with the help of service foresters in Georgia and South Carolina (Todd and Zirkel, 1949; Cruikshank and Anderson, 1955; Anderson, 1961 and 1969). The first four columns of table 6.1 show the factors and whether they were significant or nonsignificant in influencing southern pine sawtimber prices.

Sam Guttenberg and his colleagues at the Southern Forest Experiment Station have made a second series of sawtimber price studies. The data include over 2,000 sales made on National Forests in Louisiana, Mississippi, Arkansas, and Texas over

Table 6.1--Previous analysis of southern pine stumpage prices showing major factors tested and whether they were significant (at 5% probability) or not significant. 1/

FACTORS 2/	SAWTIMBER									PULPWOOD		
	1	2	3	4	5	6	7	8	8A	9	10	11
Location 3/	S	S	S	S	S	S	S	S	S	S	S	S
Volume/tree		S	S	S	N	S	S	N	S	S		
Volume/acre	S	S	N	S	S	N				S	S	S
Total volume		N	N	N	S	N	S	S	S	S	S	S
Acres in sale	S	N	N	N								S
Diameter or BA/tree			N		S	S	S	N	N			
Height			N									
Grade			N 1/			S	S	S	S			
Trees				N								
Trees/acre			N	N								
BA/acre			N				S	N	N			
Bids 4/	S		S	S	S	S	S	S	S		S	S
Distance to mill			S			N						
Lumber price 5/				S	S	S	S	S	S			
Lumber price change 6/				S	N	S	S	N	N			
Date (Month) (Jan 49=100)				S	S			N	S	S	S	S
Date squared				S			S	N	N	S		
Hardwood ratio 7/					S	N	S			S		
Volume/BA					S	S	S	N	N			
Distance to road			N			N						
Distance to mill			S								S	
R-2	NA	16-31	58	47	47	65	63	75	73	NA	59	56

1/ The studies cited were: 1. Todd and Cirkle (1949), 2. Cruckshank and Anderson (1955), 3. Anderson (1961), 4. Anderson (1969), 5. Guttenberg (1956), 6. Guttenberg and Row (1961), 7. Guttenberg and Fasick (1965), 8. Holley (1970), 9. Row and Guttenberg (1961), 10. Fasick and Sampson (1966), 11. Anderson (1969).

Table 6.1--cont.

2/ A number of nonsignificant miscellaneous variables and interactions are not listed.

3/ Various 1-0 variables were used to designate states or regions.

4/ Bids in themselves are not independent of the other factors. For pulpwood, it was the number of firms buying wood in area.

5/ Lumber price used was either price of No. 2 common boards, or in #8, No. 2 common dimension the month previous to sale.

6/ Lumber price change was from 13 months previous to sale to 1 month previous to sale.

7/ Hardwood ratio was the ratio of hardwood volume to southern pine volume in sale. Hardwood are priced separately in sale procedure.

a similar 20-year period. Several characteristics make these sales particularly suitable for econometric analysis: (a) The sales are prepared in a uniform way and at regular intervals, (b) they are intensively advertised in their locality and are sold by sealed bids, (c) sales administration follows well known and relatively uniform regulations. Factors studied in this series and whether or not they were significant are shown in columns 5 through 8 (Guttenberg, 1956; Guttenberg and Row, 1961; Guttenberg and Fasick, 1965; and Holley, 1970). A reanalysis of the Holley data from 1960-1969 using the same variables resulted in revised results shown in column 8a of table 6.1.

The third series of analyses have studied patterns of pulpwood prices from National Forest timber sales (Row and Guttenberg, 1961; Fasick and Sampson, 1966; Anderson, 1969). In general, pulpwood is sold by the National Forests using a simpler appraisal procedure than used for sawtimber. Thus far fewer factors are recorded in sales administration records. Columns 9 to 11 in table 6.1 shows the factors found to influence prices.

Review of these studies suggests the following conclusions:

1. In sawtimber stumpage prices, the most important factor is the price of lumber at the time the sale is made. Lumber prices usually account for half or more of the variation in sawtimber stumpage prices. The coefficients indicate that stumpage absorbs from 70 to 90 percent of short-run lumber price changes. In earlier studies, direction and rate of change of lumber prices were also significant. These results appear to reflect surges

of increased demand and use of byproducts.

2. The significance of time (month of sale) indicates that a number of unspecified variables have tended to increase stumpage prices over time, proportionately faster than lumber prices. Functions of month of sale have also been strongly related to prices of pulpwood stumpage, even though there has been little long-run increase. These functions appear to reflect surges of increased demand and use of byproducts.

3. Various 1-0 dummy variables representing states or market areas have been significant in all stumpage price analyses. Specific market areas are difficult to delimit, however.

4. Number of buyers who submit bids is nearly always significant. But most researchers have recognized that number of bidders is not an independent variable, but an alternate index of desirability of the timber sale. Guttenberg (1956) and Anderson (1969) found that number of bidders was closely related to total volume of the sale and volume per acre. When number of bidders was a variable in the regression equation, it reduced substantially the significance of other variables. In addition, number of bidders cannot be accurately predicted for a particular sale. Prediction equations should thus be derived without number of bidders as an independent variable.

The four foregoing types of variables serve to standardize sales data to a common market condition, location, and time period. When the variation attributed to them is removed, otherwise obscured relationships of stumpage prices to tree and stand

variables are nearly always evident.

Among the most important are:

5. Volume per sale is normally a significant influence on timber price. With increasing size of sale, unit prices of either sawtimber or pulpwood increase. This factor apparently is the result of reduced logging costs.

6. A volume per tree variable usually indicates that larger trees bring higher unit prices. In addition to its association with logging costs, volume per tree is related to average quality.

Several shortcomings of these studies of sawtimber and pulpwood prices prevent them from being used directly in the simulation model in this study. The equations developed do not cover both sawtimber and pulpwood. The units are thousand board feet of sawtimber or cords of pulpwood, which are directly related neither to each other nor to cubic feet used in the simulation model. The independent variables were those readily obtained from timber sales records, but not necessarily those variables forest managers would use to make decisions, nor which are most convenient for simulation. Finally, analyses have not tested for significance of a constant cost per sale. This cost would represent the fixed expenses borne by the logger or processor in appraisal and bidding, and for moving logging equipment to the site.

Reanalysis of southern pine stumpage data

For this study, the group of southern pine stumpage sales studied by Holley (1970) was reanalyzed to develop a stumpage

price predicting equation that would improve the relationships by:

1. Estimating prices per cubic foot, eliminating the need to convert board feet and cords to cubic foot yields and arbitrary allocation of different timber sizes and qualities to specific uses.

2. Predicting values for the entire size range of merchantable timber, including pulpwood and sawtimber.

3. Including constant values that, if significant would represent the cost of administration and for moving equipment to the tract.

The model. The reanalysis used the general concept for valuation of revenues developed in Chapter 3. The objective of the reanalysis was to estimate the total pretax revenues for the entire tract (TR), instead of estimating only unit values for inclusion into a simple appraisal equation such as (3.13). The elaborated model given in Chapter 3 divides the revenue into a fixed factor and a variable revenue based on the units of timber sold. The fixed factor is likely to be negative, since it represents a fixed cost of the timber buyer moving logging equipment and the cost of covering the entire tract, even without cutting any timber. The only variable thought likely to affect this fixed factor was acreage (A). The variable unit value was expected to be a function of a number of factors (PV_p) with p = 1, 2,... p,... np. The entire equation for total revenue, as given in (3.17) is:

$$TR_k = f(A) + Y_k^{**} * f(PV_1, PV_2, \ldots PV_p, \ldots PV_{np}) + e[E(\sigma_r)]$$

where $e[E(\sigma_r)]$ is the simulated error.

Translated into a form suitable for estimation of regression coefficients, the best form for the fixed revenue estimation was:

$$FR_k = b_f + b_a * A \qquad (6.1)$$

The variable revenue equation thought best for the analysis was:

$$VR_k = Y_k^{**} * (b_u + b_1 * VP_1 + b_2 * VP_2 \ldots + b_p * VP_p \ldots + b_{np} * VP_{np}) \qquad (6.2)$$

The entire equation can be expressed simply as:

$$TR_k = b_f + b_a * A + b_u * Y_k^{**} + \sum_{p=1}^{np} (b_p * VP_p * Y_k^{**}) + e \qquad (6.3)$$

The factors (VP) that appeared most important in the survey of the literature as being major influences on price were:

Variable	Symbol
Volume per acre (in cubic feet)	Y
Basal area per acre (in square feet)	B
Volume per tree (in cubic feet)	Y/N
Average tree diameter (in inches)	D
Average tree diameter squared	D * D
Average tree diameter cubed	D * D * D
Average total height (in feet)	H
Proportion of volume in tree grades A and B	G
Proportion in A and B grades squared	G * G
Lumber price 1 month prior to sale ($)	PRL
Lumber price times diameter	PRL * D
Lumber price times grade	PRL * G

In addition the regression included 3 dummy variables to detect differences between the 4 states and 3 dummy variables to detect cross product relationships. Of these variables, all but lumber price are simulated by the timber growing model.

Converting sawtimber sales data to the new regression form. From the data on 992 sawtimber sales made from 1960-69, the following steps produced all necessary variables:

1. Computation of numbers of trees, average diameter, and basal area by direct manipulation of the variables used by Holley.

2. Derivation of approximate height from a reverse solution of a standard equation for Scribner log rule (Schumacher and Coile, 1960).

3. Using diameter and height, computation of average cubic foot volume per tree. (Errors in estimating height are offset by using height to compute cubic volume.)

4. From average volume per tree and number of trees, the total cubic volume per sale and volume per acre.

Developing comparable pulpwood data. The original data for recent pulpwood sales unfortunately did not have sufficient data to derive the same variables. In selling pulpwood, estimates of average diameter and basal area are not used in the appraisal process and are thus not computed. The best recourse was to simulate a group of 500 pulpwood sales according to diameter and height to be expected of pulpwood, and the ranges of total volume and volume per acre reported in Row and Guttenberg (1961). It was assumed that one-fourth of the sales were from each of the four states originally sampled. The variables were uniformly distributed within the following ranges using a random number generator:

Average diameter from 6 to 9 inches

Height in feet using random ratios of .7 to 1.3 of height predicted from $H = 6 + 6 * D$

Volume per acre cord from 1 to 4 cords

Acres in sale from 200 to 1200

Using the cubic foot volume equation used in this study, the remaining variables could be derived directly.

The pulpwood was priced according to the relationships found by regression and reported in Row and Guttenberg (1961). To this estimate of price was added a normally distributed random error of plus or minus .165 of estimated value--approximately the error of observation found in that study. The data for the original study pertained to the late 1950's and early 1960's. Since a similar level of pulpwood stumpage prices prevailed during the late 1960's, the price relationship used appeared a reasonable approximation of prices that might have been obtained during the same period as Holley's sawtimber study.

It would also have been desirable to include a measure of pulpwood value at a further stage of processing, but the only approximate prices are for delivered pulpwood. These are relatively inflexible prices set by pulp companies. They have not been shown to influence pulpwood stumpage prices significantly.

In order not to introduce a bias, lumber prices for the pulpwood observations were simulated to vary around the same average ($91.50 per MBF) and standard deviation ($10.50) as Holley's sawtimber sales. But they did not influence the pulpwood prices. Since trees must be 12 inches in diameter or larger to have appreciable proportions of high grade logs, pulpwood was assumed to have no grade A or B trees. The simulated pulpwood sale data were thus comparable to that from the sawtimber sales except

for size. Average values of each variable for each set of data shown in table 6.2, together with the coefficient of variation for each variable after weighting by total volume.

Regression results. The coefficients of the significant variables in the model are presented in table 6.3. Both the simple weighting and iterative weighting procedures described in Chapter 4 were used. The simple weights assumed the variance of the dependent variable was proportional to the square of total volume.

For all analyses--sawtimber, pulpwood, and sawtimber and pulpwood combined--the regression results using both weighting procedures are strikingly similar. The most important variables were the same in each case, though coefficients for the minor variables differed somewhat between techniques. The amount of variance removed was almost identical, about 95 percent for all regressions. Most remarkable was that 17 of 21 variables were significant at the .05 probability level.

Because of the interrelationships of the variables it is often not evident whether the coefficients are reasonable. The reasonableness of the equation for the combined sawtimber and pulpwood was examined by computing the values of predicted average price per cubic foot under various assumptions.

First effects of diameter and height and grade are shown in table 6.4. The prices assume a sale of 1,000 cubic feet per acre on 200 acres with lumber prices at $100 per MBF. The effects of diameter and grade are in the direction and magnitude

Table 6.2--Variables used in stumpage price analyses with averages and coefficients of variation (CV).

Variable		Sawtimber		Pulpwood		Sawtimber & Pulpwood	
		Mean	CV	Mean	CV	Mean	CV
Prime	Symbol						
Constant	K	1.000	.0	1.000	.0	1.000	.0
Area in Acres/1000	A	.932	.8	.813	.4	.892	.8
Total volume in cu. ft./1000	TY	283.867	.7	152.509	.6	239.875	.8
Secondary (all * TY).							
Volume in cu. ft./acre	Y	417.647	1.3	159.993	.8	373.717	1.5
Basal area in sq. ft./acre	B	18.090	1.3	8.347	.9	16.643	1.5
Volume in cu. ft./tree	Y/N	27.092	.9	5.242	.7	22.402	1.2
Avg. diameter in inches	D	14.612	.8	7.560	.6	13.092	.9
Avg. height in feet	H	64.901	.7	51.360	.6	61.828	.8
Grade (% A + B)	G	.550	.9	.0	.0	.433	1.3
Grade ^{2}	G*G	.350	1.1	.0	.0	.275	1.6
Lumber in $ per MBF price	L$	91.109	.7	91.391	.6	91.170	.8
Lumber * diameter	L$*D	1333.041	.8	690.500	.6	1194.651	1.0
Lumber * grade	L$*G	50.522	1.0	.0	.0	39.765	1.4
Dependent							
Total value/1000	TV	50.053	.9	10.520	.6	36.814	1.1
(Value per cubic foot)	V	.176		.069		.153	

Table 6.3--Regression coefficients from stumpage price analyses with T-test values

	Sawtimber				Pulpwood				Sawtimber and pulpwood			
	Simple		Iterative		Simple		Iterative		Simple		Iterative	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Constant	-.320692	2.7	-		-		-					
Acres	n.s.		-		-		-		-1.087915	3.5	-1.392809	3.8
Total volume	.866541	8.3	.983716	6.8	.017202	2.1	-.020270	3.4	.415936	18.2		22.3
Descriptive												
Volume/acre	.000100	3.8	.000144	6.7	.000033	4.2	.000026	3.5	.000156	9.1	.000197	15.0
Basal acea/acre	-.001810	2.9	-.002840	5.9	-		-		-.003278	8.3	-.004211	15.4
Volume/tree	.005806	5.9	.000704	2.0	-		-		.001764	6.1	.002157	7.7
Avg. diameter	-.072793	9.9	-.090068	8.3	.005878	9.6	.005670	10.2	-.040305	21.9	-.040241	20.5
Avg. height	-.002115	6.6	n.s.		-		-		-.000873	7.0	-.00918	
Grade	n.s.		.124534		-		-		n.s.		n.s.	3.4
Grade^2	n.s.		n.s.								-.041549	
Lumber price	-.006429	5.9	-.010517	6.5	-		-		-.003719	-15.9	-.003240	18.4
Lumber price times by diameter	.000678	9.2	.001057	8.9	-		-		.000497	26.5	.000463	22.7
Lumber price by grade	.000526	9.0	-.000852	2.0	-		-		.000597	12.4	.001122	9.3
Location												
Ark.	.017414	2.3	-.113082	3.6	-		-		-.009945	6.6	-.006009	-5.8
Miss.	-		-		.008486	3.4	.001588	2.8	-		.007402	7.3
Tex.	-		-.007776	3.2	.002775	8.5	-.002720	10.0	-.003555	7.3	.003063	8.8
Ark. * D	.001533	2.8	.009405	4.2	-		-		.001535	8.4	.000720	6.7
Miss. * D	-.000135	2.8	-		.000653	2.0	-.000536	1.5	-		.000591	6.3
Tex. * D	-.000750		-		-		-		-		-	
R^2	.9592		.9556		.9407		.9420		.9581		.9521	

Table 6.4 --Timber prices per cubic foot by average stand diameter, total stand height, and proportion of grade A and B trees.

Diameter	Total stand height in feet					
	40.	50.	60.	70.	80.	90.
(Inches)	(Dollars per cubic foot)					
	Grade = 0.					
6.	0.071	0.060	0.050	0.039	0.029	0.018
8.	0.108	0.100	0.092	0.083	0.075	0.067
10.	0.137	0.132	0.127	0.123	0.118	0.113
12.	0.160	0.159	0.158	0.158	0.157	0.156
14.	0.177	0.182	0.186	0.190	0.194	0.199
16.	0.190	0.200	0.211	0.221	0.231	0.241
18.	0.200	0.217	0.234	0.251	0.268	0.285
20.	0.208	0.232	0.257	0.281	0.306	0.331
	Grade = 1.					
6.	0.090	0.080	0.069	0.059	0.048	0.037
8.	0.127	0.119	0.111	0.103	0.095	0.086
10.	0.157	0.152	0.147	0.142	0.137	0.132
12.	0.179	0.179	0.178	0.177	0.176	0.176
14.	0.197	0.201	0.205	0.210	0.214	0.218
16.	0.210	0.220	0.230	0.240	0.250	0.261
18.	0.219	0.236	0.253	0.270	0.287	0.304
20.	0.227	0.252	0.276	0.301	0.325	0.350
	Grade = 1.					
6.	0.130	0.119	0.109	0.098	0.088	0.077
8.	0.167	0.159	0.151	0.142	0.134	0.126
10.	0.196	0.191	0.186	0.182	0.177	0.172
12.	0.219	0.218	0.218	0.217	0.216	0.215
14.	0.236	0.241	0.245	0.249	0.254	0.258
16.	0.249	0.260	0.270	0.280	0.290	0.300
18.	0.259	0.276	0.293	0.310	0.327	0.344
20.	0.267	0.291	0.316	0.340	0.365	0.390

anticipated. Figure 6.2 shows the stumpage price data are comparable to those derived by computing residuals (McClay, 1970, shown in figure 6.1).

The influence of the additional major variables--total acres, volume per acre, and thus total volume--is shown in table 6.5 for 3 average diameters. For each diameter, height was equal to 36.8 plus 1.9 times diameter, the average relationship for all observations. The table shows the strong advantage of large sales and heavy cuts per acre. This appears to be a reasonable estimate of the influence of area and density of cut on costs of logging and administration.

Similarly, effects of lumber price and grade are shown in table 6.6 for various diameters. The results indicate little effect in small trees but major influences on larger ones.

Tables for other equations were similar in all important aspects. While these results are no strong recommendation for using the iterative weighting technique, they show that the technique can produce comparable results. Because the iterative weighting technique appears conceptually superior, the iterative equations for sawtimber and pulpwood combined was used to price the outputs of the study.

Patterns of variance of the estimating equation

The residuals obtained from subtracting the solutions of the combined sawtimber and pulpwood equation from observed sale values indicated a strong pattern of variance. As described

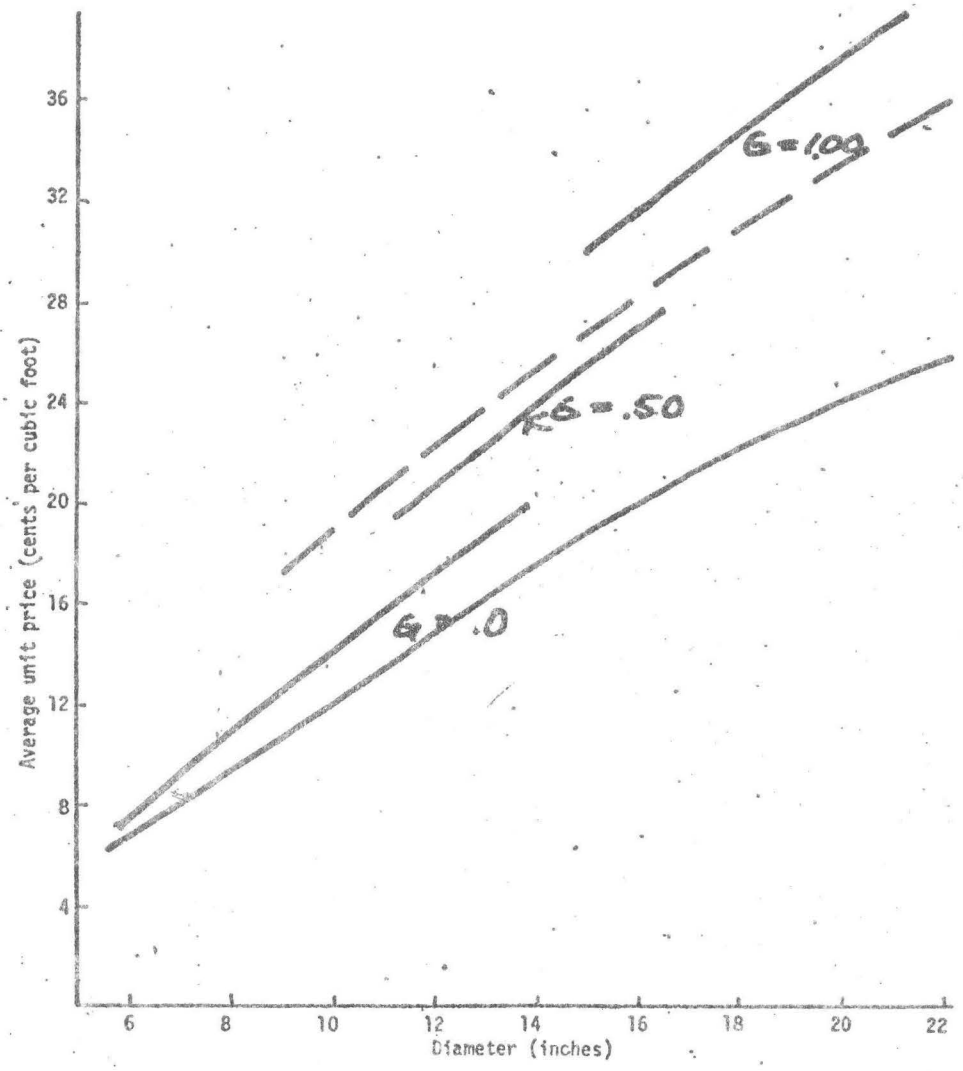
Table 6.5 --Timber prices per cubic foot by volume per acre, size of tract, and diameter.

Tract size	Volume per acre in cubic feet					
	200.	500.	1000.	1500.	2000.	3000.
(Acres)	(Dollars per cubic foot)					
	Diameter = 6.					
10.	0.0	0.025	0.060	0.080	0.095	0.123
20.	0.007	0.048	0.071	0.087	0.101	0.127
40.	0.035	0.059	0.077	0.091	0.104	0.129
80.	0.049	0.065	0.080	0.093	0.105	0.130
160.	0.056	0.068	0.081	0.094	0.106	0.130
320.	0.060	0.069	0.082	0.094	0.106	0.130
640.	0.062	0.070	0.082	0.094	0.106	0.131
1280.	0.063	0.070	0.082	0.095	0.107	0.131
2560.	0.063	0.070	0.083	0.095	0.107	0.131
	Diameter = 12.					
10.	0.047	0.122	0.156	0.176	0.192	0.219
20.	0.103	0.144	0.168	0.183	0.197	0.223
40.	0.132	0.156	0.173	0.187	0.200	0.225
80.	0.146	0.161	0.176	0.189	0.202	0.226
160.	0.153	0.164	0.178	0.190	0.202	0.227
320.	0.156	0.166	0.178	0.191	0.203	0.227
640.	0.158	0.166	0.179	0.191	0.203	0.227
1280.	0.159	0.167	0.179	0.191	0.203	0.227
2560.	0.159	0.167	0.179	0.191	0.203	0.227
	Diameter = 18.					
10.	0.142	0.217	0.251	0.271	0.286	0.314
20.	0.198	0.239	0.262	0.278	0.292	0.318
40.	0.226	0.250	0.268	0.282	0.295	0.320
80.	0.240	0.256	0.271	0.284	0.296	0.321
160.	0.248	0.259	0.272	0.285	0.297	0.321
320.	0.251	0.260	0.273	0.285	0.297	0.322
640.	0.253	0.261	0.273	0.286	0.298	0.322
1280.	0.254	0.261	0.274	0.286	0.298	0.322
2560.	0.254	0.262	0.274	0.286	0.298	0.322

Table 6.6--Timber prices per cubic foot by lumber price level, preparation of grade and diameter.

Lumber price	Proportion of volume in grade A and B trees 0.0	0.2	0.4	0.6	0.8	1.0
(Dollars)	(Dollars per cubic foot)					
	Diameter = 6.					
70.	0.070	0.068	0.069	0.074	0.081	0.092
80.	0.068	0.068	0.072	0.079	0.089	0.102
90.	0.065	0.068	0.074	0.083	0.096	0.112
100.	0.062	0.067	0.076	0.088	0.103	0.121
110.	0.059	0.067	0.078	0.092	0.110	0.131
120.	0.057	0.067	0.080	0.097	0.117	0.140
140.	0.051	0.066	0.085	0.106	0.131	0.160
160.	0.046	0.066	0.089	0.116	0.146	0.179
200.	0.034	0.065	0.098	0.134	0.174	0.217
	Diameter = 12.					
70.	0.100	0.098	0.099	0.103	0.111	0.122
80.	0.120	0.120	0.123	0.130	0.140	0.154
90.	0.139	0.142	0.148	0.157	0.170	0.186
100.	0.158	0.164	0.172	0.184	0.199	0.218
110.	0.178	0.186	0.197	0.211	0.229	0.249
120.	0.197	0.208	0.221	0.238	0.258	0.281
140.	0.236	0.252	0.270	0.292	0.317	0.345
160.	0.275	0.296	0.319	0.346	0.376	0.409
200.	0.353	0.383	0.417	0.453	0.493	0.536
	Diameter = 18.					
70.	0.128	0.126	0.127	0.131	0.139	0.150
80.	0.170	0.170	0.174	0.181	0.191	0.204
90.	0.212	0.214	0.220	0.230	0.242	0.258
100.	0.253	0.259	0.267	0.279	0.294	0.312
110.	0.295	0.303	0.314	0.328	0.346	0.366
120.	0.337	0.347	0.361	0.377	0.397	0.421
140.	0.420	0.435	0.454	0.476	0.501	0.529
160.	0.504	0.524	0.547	0.574	0.604	0.637
200.	0.671	0.701	0.734	0.771	0.811	0.854

Figure 6.2--Stumpage price relationships found in reanalysis of price data from National Forest sales. The trends are superimposed on figure 6.1.



in Chapter 4, this was measured by solving a secondary regression of the squared error of each observation on the estimated total value. The equation form was:

$$e^2 = a * TR^b$$

or:
$$\log_{10}(e^2) = \log_{10}(a) + b * \log_{10}(TR) \quad (6.4)$$

The regression analysis estimated the coefficients as:

$$\log_{10}(e^2) = .4245 + 1.0573 * \log_{10}(TR) \quad (6.5)$$

The relationship will be used in the simulation system to estimate the variance of each estimate of total receipts from each sale. The square root, or the standard error of the estimate, can be used to simulate a normal deviation in conjunction with a random number generator. This deviation, when added to estimated total sale value, simulates the stochastic variation in expected receipts.

The standard errors of expected prices per cubic foot were computed assuming that identical stands of 2000 cubic feet nominally valued at 25 cents per cubic foot are sold from different sized tracts. The standard error drops from 7.8 cents on 100 acre tracts to less than 2 cents for large tracts. The increased uncertainty of price is in addition to the lower prices for timber from small tracts. Thus small sized tracts suffer a double penalty.

Additional quality factors

In applying the price regression to simulations of stands, a deficiency in the equation in respect to another quality

factor became apparent.

When timber grows extremely fast because of low stocking, wood with wide rings is produced. In manufacture of lumber and plywood these wide ring bands cause high variability in drying, straightness, and strength. Southern pine lumber grading rules limit medium and dense lumber to wood with 4 or 6 more rings per inch. Wood with wider rings will not qualify for dimension grades. (Southern Pine Inspection Bureau, 1968).

Thus timber with very fast diameter growth rates is worth much less than similar timber in diameter and height grown more slowly. Nearly all timber sold from National Forest stands from which the regression data originated is slow grown, so the effect did not appear in the regression.

To correct the stumpage prices, a factor was applied to prices for timber whose average growth rate has been more than .4 of an inch a year (or 5 rings per inch). The most suitable form was:

$$P_k^* = P_k \; / \; [1 + D_t \; / \; (T * 2)] \qquad (6.6)$$

where D is average stand diameter and T is stand age.

At extreme growth rates this correction factor reduces the price of large timber to the level of pulpwood prices. This is the product for which such very rapidly grown timber would probably be used.

Trends in southern pine lumber prices

The foregoing section developed an equation for southern pine timber prices that is applicable for all types of marketable

southern pine timber. The most important single variable, particularly for the sawtimber portion of the data, is average southern pine lumber price. This agrees well with the derived demand origin of stumpage prices. Ideally it would have been preferable to incorporate also a measure of the price of pulpwood at a point along the train of processing steps toward paper products.

In application of the equation to pricing timber yields simulated by the study's model, a price for southern pine lumber must be assumed or projected. As the following discussion will indicate, there are strong reasons to believe that the southern pine lumber prices will tend to rise relative to all prices in the next few decades. This section will discuss the past trends and develop estimates of the rate and likelihood of the increase in price.

Price projection methodology

A substantial portion of economic literature pertains to projections of demand, supply and price of various products and in different economic sectors. Price cannot be projected independently of consideration of likely trends in demand and supply, nor can either demand or supply be meaningfully forecast without reference to possible price patterns.

Though most southern pine products are sold in southern or nearby states, their markets interpenetrate those from other regions. Lumber, plywood, and paper from various producing regions are particularly close substitutes, with few distinguishing qualities.

Market areas continually shift according to prices and transportation costs. Thus the markets pertinent to projection of southern pine prices are national markets for all major forest products.

Several approaches to a comprehensive supply and demand study are possible. Among them are disaggregation of the demand into component end uses and estimation of demands for each under various conditions (including prices). The aggregate demand is the sum of the components, and the aggregate supply is sum of potential supply sources. A basically different approach is fitting historical data to an econometric model. Data availability generally limits such models to rather large aggregates of products, industry components, or major regions.

Such a price study is far beyond the limits of this study, and for practical purposes unnecessary. Major studies using all major approaches have been made. They indicate roughly the same conclusions, though emphasis, specific projections, and cause effect relationships often differ.

Among the major studies are the Forest Service's Timber Resources in America's Future (USDA Forest Service, 1958) and Timber Trends in the United States (USDA Forest Service, 1965) and a new study just being completed. These studies have included detailed consideration of each significant end use and supply from each region and ownership class. The latest study has estimated the impacts of various patterns of price increases on demand.

Econometric studies have developed similar estimates of future demand and supply patterns from fitting historical series

to simultaneous equation models. Most notable are those of McKillop (1967), and Mills (1972). Dutrow (1971), and Teeguarden and McKillop (1972) have econometric models for single species other than southern pine.

Both types of studies provide a number of indications that past trends and patterns are likely to continue in the foreseeable future. In general, review of these studies suggests that:

1. Demand is highly dependent on shifts caused by fluctuations in housing construction. There is no evidence that demand for forest products will not remain highly inelastic even though individual markets will continue to be lost to other products.

2. Supply will be increasingly composed of public timber sales and in the distant future, highly dependent on intensity of timber management activities. Thus, the supply will not become more elastic. The prospect is for continued wide fluctuations in the market for the major solid wood products. Pulp and paper markets, however, may remain relatively stable.

3. Demand will continue to increase at a faster rate than supply, at least for the remainder of the century. This implies continued increases in prices in the same direction and most likely in the same general magnitude as in the past. Because of the instability in major solid wood markets, the increases are likely to occur in surges, as price increases have happened in the past.

Lumber price history

Historically, prices for lumber in the United States have increased in marked steps or stages. Briefly, important increases in prices occurred about 1890, during and after World War I, and especially from 1946 through the Korean War. (During the World War II years, prices were controlled by Office of Price Administration, and are thus omitted from the analysis). In each case a surge in construction caused an increase in lumber demand that could not be met by the static or declining timber supply in establishing producing regions. The lumber industry sought new supplies of timber in hitherto unexploited areas--the Pacific Northwest, the South, and in recent years the Rocky Mountain States and British Columbia--and encouraged public agencies such as the Forest Service to offer more timber for sale.

Annual southern pine lumber and sawtimber stumpage price series are shown in table 6.7. Data for years 1910 to 1941 are derived from Steer (1938, 1948). Since 1947 they are based on the Bureau of Labor Statistics indexes for average wholesale price for reported grades, widths, and lengths, f.o.b. mill. Since the BLS index components are generally higher-valued items that average mill output, a weighted dollar value of the BLS series would exceed the net average realization value at the mill. Used instead were average realization values based on a Forest Service tabulation of average realization prices for a sample of 29 representative mills purchasing Forest Service southern pine timber throughout the South for 1966-70. Dividing

Table 6-7--Annual southern pine lumber and sawtimber stumpage prices, 1910-70, adjusted to constant dollars

Year	Sawtimber price	Lumber price[1/]	Year	Sawtimber price	Lumber price
1910	3.44	30.53	1938	15.05	46.91
1911	6.99	41.45	1939	12.10	49.53
1912	3.44	30.37	1940	9.27	52.68
1913	3.94	26.94	1941	20.02	56.60
1914	6.89	47.22	1947	11.90	89.91
1915	4.90	34.65	1948	16.54	91.10
1916	6.00	32.49	1949	20.91	86.61
1917	4.69	31.35	1950	27.20	93.44
1918	3.71	36.08	1951	31.71	89.94
1919	4.33	40.19	1952	36.30	93.44
1920	4.61	45.00	1953	32.70	93.01
1921	6.14	38.59	1954	28.33	89.54
1922	4.69	47.45	1955	30.43	92.85
1923	4.83	57.42	1956	34.46	93.09
1924	5.79	52.55	1957	28.20	86.98
1925	5.01	49.00	1958	27.45	84.48
1926	5.82	51.38	1959	31.01	87.14
1927	5.93	48.22	1960	30.38	85.08
1928	6.02	49.25	1961	23.68	82.33
1929	5.05	52.26	1962	22.91	82.00
1930	6.00	47.24	1963	22.18	81.98
1931	7.55	45.18	1964	24.52	81.90
1932	6.97	38.70	1965	27.41	81.74
1933	6.63	52.64	1966	32.30	86.92
1934	6.27	56.00	1967	31.99	86.60
1935	9.11	44.18	1968	34.38	90.92
1936	10.23	49.83	1969	40.55	102.29
1937	9.95	49.86	1970	33.38	89.37

[1/] Sawtimber prices adjusted to international--1/4 inch rule and to growing stock standards.

the average realization value by the average price index for these years yielded a 1967 index value of $81.24 per thousand board feet.

The all-commodity BLS wholesale price index represents most closely the changing value of the dollar in raw materials markets. Division of both timber and lumber prices by the index (1967-100) converted the values into equivalent 1967 dollars.

Furthermore the sales unit for Forest Service timber sales is the Scribner log rule. Scribner rule underestimates volumes of logs compared with International 1/4-inch rule, which closely approximates the actual lumber recovery and is the standard Forest Survey sawtimber unit. The values were thus corrected to International 1/4-inch rule, and further slightly adjusted for the fact that the timber actually estimated to be cut and paid for is somewhat lower than growing stock volume since some is in trees not capable of utilization. The factors are 1.150 for conversion to International rule and 1.042 for utilization.

Similar sets of quarterly lumber and stumpage prices for the last 15 years are shown in table 6.8. A seasonal variation analysis, using an analysis of variance of quarterly ratios to a 5-quarter weighted running average, showed no consistent seasonal pattern for either lumber or timber.

Rates of increase in lumber and timber prices

The trends in constant dollar lumber and timber prices show upward trends, with the rise in timber prices substantially

Table 6-8--Quarterly southern pine lumber and sawtimber stumpage prices, 1957-III to 1971-II, adjusted to constant dollars

Year Q	Lumber price	Sawtimber price[1/]	Year Q	Lumber price	Sawtimber price
1957 III	27.60	86.35	1964 III	24.77	82.70
1957 IV	26.56	86.27	1964 IV	25.39	82.60
1958 I	26.69	85.03	1965 I	25.60	79.90
1958 II	26.14	84.33	1965 II	26.31	80.06
1958 III	29.17	84.68	1965 III	26.21	81.73
1958 IV	28.30	85.97	1965 IV	30.01	83.74
1959 I	29.88	85.97	1966 I	29.42	83.77
1959 II	30.00	87.53	1966 II	32.27	88.44
1959 III	32.95	88.92	1966 III	34.10	80.25
1959 IV	31.42	89.35	1966 IV	32.52	87.54
1960 I	32.21	88.19	1967 I	31.17	85.48
1960 II	30.30	87.50	1967 II	38.78	85.81
1960 III	29.62	85.35	1967 III	32.16	87.20
1960 IV	25.52	83.29	1967 IV	33.10	88.90
1961 I	24.41	82.34	1968 I	32.27	89.96
1961 II	22.95	83.21	1968 II	33.68	94.47
1961 III	21.75	83.03	1968 III	33.52	97.48
1961 IV	23.61	83.03	1968 IV	36.04	101.74
1962 I	23.63	82.78	1969 I	42.43	105.92
1962 II	21.95	83.03	1969 II	43.62	110.23
1962 III	22.16	82.43	1969 III	35.93	96.24
1962 IV	23.27	81.91	1969 IV	36.43	93.22
1963 I	22.56	81.31	1970 I	32.01	90.11
1963 II	21.93	81.91	1970 II	33.38	88.94
1963 III	22.03	83.12	1970 III	33.82	89.38
1963 IV	21.46	82.51	1970 IV	32.89	90.92
1964 I	22.75	82.87	1971 I	35.67	106.47
1964 II	24.35	83.12	1971 II	34.82	113.82

[1/] Sawtimber prices adjusted to international--1/4 inch rule and to growing stock standards.

steeper. Trends in real or constant dollar lumber and timber prices can be indicated by rates of increase in two forms. These are:

1. Constant real price increases. In this form the increases in prices are assumed to be the same each year:

$$P_t = a + b * T \qquad (6.7)$$

in which a is the price in the base year and b is the annual rate of increase. (In the regression the base year is arbitrarily set at 100). Fitting the data to this form resulted in the first set of rates of increase in table 6.9. The time periods used were the entire 1910-1970 span, the segments from 1947-70, and the quarterly data from mid-1957 to mid-1970. Though the R^2 estimates of variation accounted for are rather high (except for the 1947-1970 period), the fits are only approximate. The historical series, the trend, and projections into the future are shown in figure 6.4. Extrapolated into the future, projected prices using these rates rise moderately.

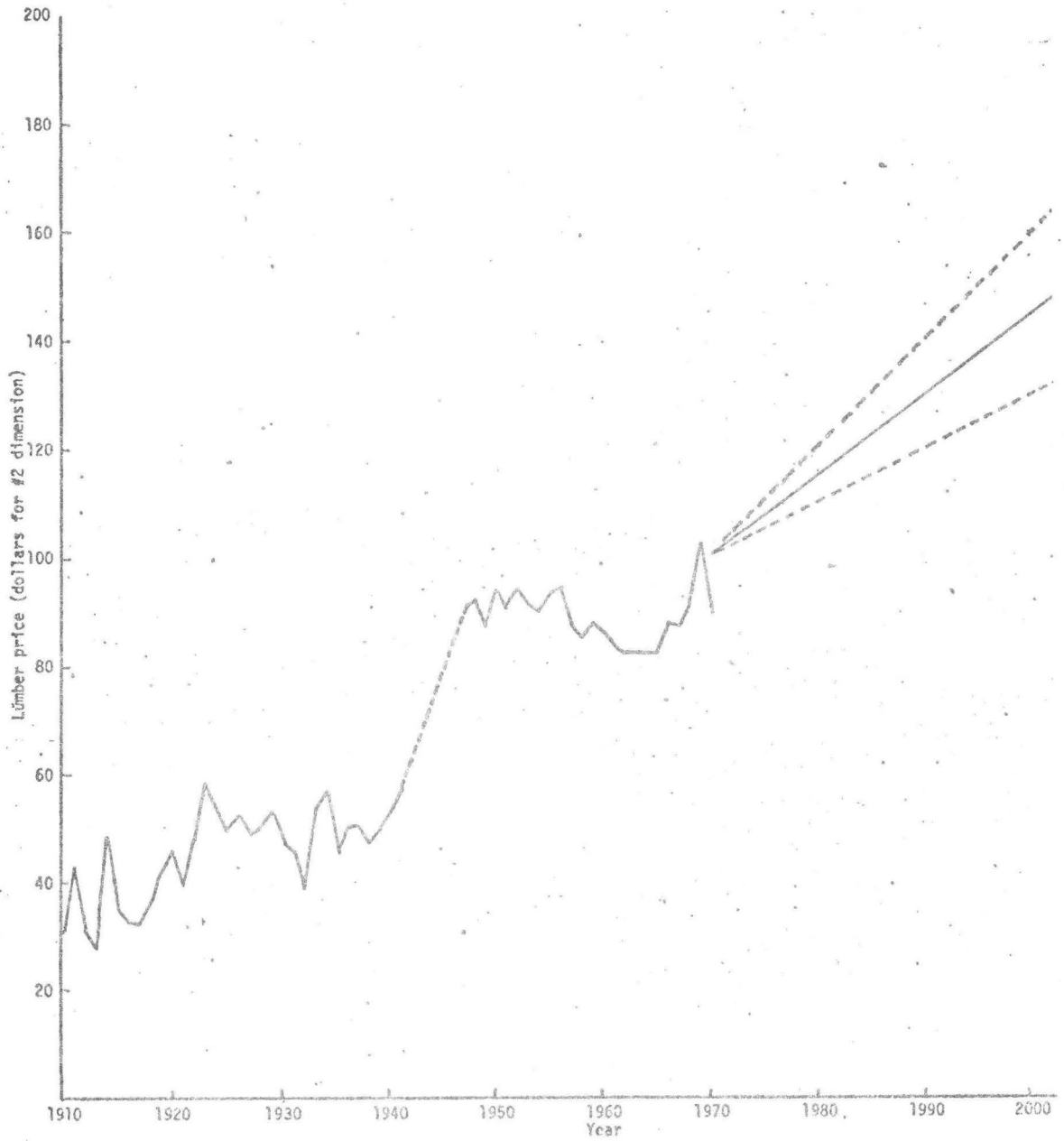
A feature of these projections is that for any rate of annual change, the proportional increase or decrease in prices would decline year by year. Such a pattern of future price increase is appropriate if one assumes that lumber will encounter stiffer competition as relative prices rise.

2. Proportional real price increases. In this form increases in price are a constant proportion of the previous year's price or at a compounded percent rate:

Table 6.9--Coefficients for trend regression of southern pine lumber and timber prices.

Regression	a coef.	b coef.	R^2	1970 Trend est.	Rate of increase
Constant real price increases					
1910 - 1970					
Lumber	17.929	1.135	.836	97.91	1.16
Timber	- 7.23	.582	.832	33.76	1.76
1947-1970					
Lumber	96.97	- .144	.041	86.78	- .16
Timber	3.05	.429	.221	33.30	1.29
1957III - 1971II					
Lumber	22.16	1.016	.310	93.81	1.24
Timber	- 20.18	.767	.341	33.95	2.26
Proportional real price increases					
1910 - 1970					
Lumber	1.4420	.00823	.837	104.50	1.91
Timber	.3492	.01806	.888	41.89	4.24
1947 - 1970					
Lumber	1.9910	-.00076	.049	87.26	- .18
Timber	.9661	.00080	.237	34.04	1.85
1957III - 1971II					
Lumber	1.6387	.00469	.309	93.37	.78
Timber	.7573	.01090	.317	33.30	2.54

Figure 6.3--Trend in southern pine lumber prices, 1910 to 1970, and projection to 2000 on linear trend assumed in this study. Dotted lines indicate a standard deviation in owner's price expectations.



$$P_t = a * (1 + b)^T \qquad (6.8)$$

or $$\log_{10}(P_t) = \log_{10}(a) + \log_{10}(1 + b) * T$$

The percent rates of increase from fitting this form to the data are shown in the second half of table 6.9. The results extrapolated into the future suggest a substantially more rapid increase in future years. This is also shown in figure 6.3.

Though the results will not be shown in detail, similar determinations of rates of price increases were made for Douglas-fir in western Washington and western Oregon, and ponderosa pine in California. The rates for these species are influenced by the trends in demand for the types of lumber predominately produced (ponderosa pine is often cut into boards, and southern pine and Douglas-fir into structural dimension). In all three species the timber price increases were more erratic and less consistent than increases for lumber prices. This supports the approach taken in this study in determining the present pattern of prices. Stumpage prices are best determined by relating them to the more stable lumber prices.

Lumber price trends selected for study

The rates of increase for southern pine lumber run from just .13 a year for the period 1947-70 to 1.86 percent a year for the longest period. The 1947-70 period was heavily influenced by the fact that during the first years, prices had climbed rapidly because the southern pine was the most available species to provide lumber for the post World War II housing

boom. From the early 1950's to 1965, the southern pine market had difficulty in maintaining earlier price increases during a series of indifferent housing construction years. The series for the years from 1957-70 represent a more normal period in which the southern pine lumber prices rose about 1.13 percent a year. The long 1910-1970 period includes a number of price increases which are unlikely in the foreseeable future.

The price history in most recent 4 years, however, appears to suggest a more substantial rise in prices may have occurred and continued price rise in the next decade or two may exceed the rate later in the 1900's. The most recent analysis of timber trends suggests that high prices may reduce demand to rates more in balance with growth. Thus, the linear assumption of price increases may be more likely than the exponential form.

For these reasons, the following assumptions were assumed for this study. The base price of #2 common dimension, the variable used in the price pattern equation, is $100--about a medium level for recent years. The most likely rate of lumber price increases assumed are $1.50 a year for the median estimate, with a standard error of $.50 a year. At two standard errors, the low estimate would imply there will be little relative lumber price increases, the high estimate would indicate that the lumber price would rise at $2.50 percent a year.

These estimates of lumber price increases are plotted in figure 6.4 until the year 2010, or approximately 40 years in the future.

Short-term variation in lumber prices

The logarithmic regression for the quarterly lumber price data gives an indication of the variation in lumber prices that would be encountered by the individual owner selling his timber. After removing the influence of trend, the standard error of the regression equation, in logarithmic units, was .029. This indicates that an individual owner would expect to sell in markets where the lumber prices fluctuated with a standard of error of 7.9 percent of the base price.

Summary

This chapter develops a price relationship that incorporates the factors thought to influence southern pine stumpage for contractual data from National Forest timber sales. The resulting estimating equation gives satisfactory estimates of prices for a wide variety of situations and ranges of timber size and quality. The variance pattern of this overall stumpage price equation will permit simulation of the variance of stumpage prices to individual owners.

The primary exogenous explanatory variable is southern pine lumber prices. The past trends for lumber prices indicate that prices are likely to continue rising. The variance of the quarterly stumpage prices, with the time trend removed indicates the approximate degree of variation of the lumber price market that will affect the prices that individual owners will receive.

Chapter 7

DETERMINANTS AND TRENDS IN TIMBER GROWING COSTS

Economic evaluation of timber growing requires realistic estimates of costs of practices required for establishing, maintaining, protecting, and selling timber. Developing costs estimates of forestry operations is more difficult than are similar efforts in most industries.

The main problems are extreme variability of work performed, of operating conditions, and of quality of results desired. As mentioned in Chapter 2, timber growing involves a dozen or more major practices. Often each practice can be performed several ways. Practices such as site preparation and planting involve a single major concentrated effort; other practices such as fire protection involve continued custodial care. Site preparation and stand conversion are equipment intensive, cull tree removal and thinning are labor intensive.

Conditions under which practices are performed may cause many-fold differences in cost. For example, planting costs depend on whether the land is open fields or cut-over forest; cull tree removal and thinning costs depend on number of trees removed, number left, and undergrowth. In addition, wide ranges in land conditions, crew organization and training, and supervision cause large variations in costs. In effect, each timber growing treatment is unique.

Different intensities of work performed in silvicultural operations may involve intentional tradeoffs between improved

results and additional cost. For example, it may be cheaper to have less complete site preparation and expected increased planting costs and lower survival. Complete cull tree removal may not be economical since some trees not worth killing should be bypassed.

Chapter 6 developed output prices from an econometric analysis of contractural evidence from actual timber sales, instead of using synthetic values. Similarly, this chapter develops cost estimating procedures from contractual evidence from records of contracts for silvicultural treatments. Aside from being a more positive and realistic approach, the method permits estimation of cost variability. This study attempts to improve cost estimating by also including effect of size of tract and operating conditions.

Types of cost information needed for timber growing practices are similar to those needed for prices of timber outputs. They are:

1. What is the current pattern of costs of typical silvicultural practices for various sites and operating conditions in a forest type, and how much do they vary?

2. What is the direction, magnitude, and likelihood of future trends in costs?

As with price analysis, substantially more can be said in answer to the first question than to the last. The sections of this chapter take up these two problems in order.

Patterns of current costs

Because costs of treatment vary substantially by factors

according to such functional relationships. The task of this analysis is to develop the relationships of cost to major decision or land condition variables, and measure the range of variation caused by other variables.

Techniques of cost analysis used in timber growing

The source and type of data used in cost study generally limits the method of analysis used. The combination of extreme variation and lack of direct data sources has lead to a wide spectrum of alternative analytical approaches in the published literature:1/

1. Technical studies of specific practices. Such studies often include estimates of average costs of various methods, and occasionally mention influences of different operating conditions. Examples are Keister (1968) and Chappelle (1956) for thinning, Carvell (1956), Jokela and Lorenz (1955) and Peevy (1960) for cull tree removal, Fillip (1968) for site preparation and Burns and Hebb (1972) for type conversion. Unfortunately such studies generally apply to a limited geographic area or range of conditions.

Often this research includes cost studies where time trials are taken under experimental conditions. Experimental cost

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1/Forest industry firms have also reputedly developed cost accounting systems of varying degrees of complexity and accuracy.

studies can obtain data under the specified conditions, and compile labor and equipment requirements accurately. Unfortunately crew organization and operation conditions are often not typical and overhead is difficult to estimate.

2. Surveys of timber growing costs. Survey studies are generally based on estimates from experienced forest managers. In the South the only major series of consistent cost data published are based on surveys of industrial forest management (Worrell, 1953, Yoho and Fish, 1961; Somberg, Eads, and Yoho, 1963; and Yoho, Dutrow, and Moak, 1969). Such surveys suggest ranges of costs that forest managers have experienced, but do not effectively develop the influence of operation conditions. Results are limited because forest managers generally are reluctant to provide detailed information on costs for typical situations or practices. Usefulness is also reduced by the varying interpretation of items of overhead to be included, and inability to relate costs to many of the factors that influence them.

3. Analytical studies of administrative records. The few statistical studies of forest practices, such as Wikstrom and Alley (1967), do not apply to the South. These studies suggested methods, however, that were used to develop cost patterns for this study. Several published studies have used administrative project records of silvicultural operations kept by forestry organizations. Wikstrom and Alley analyzed Forest Service project information covering Montana, Northern Idaho, and Eastern Washington. Hilliker, Webster, and Tritch (1969) used project records of the State of Wisconsin, largely on state lands. Conkin (1971)

gathered similar data from sources throughout the North. Manthy (1970) used records of costs of Agricultural Conservation Program financed projects on private land. Project records, however, are generally set up for accounting purposes. Often they do not contain information on important variables that may have influenced costs, and include no or incomplete overhead costs.

The source of data chosen. A survey of sources of data to develop cost patterns and variability did not reveal sufficient information on southern forestry practices to develop the desired functions. The most pertinent source was Forest Service records of contracts to firms who specialize in providing timber growing services in various parts of the United States. The contracts generally provide information on most major cost-affecting factors. This type of data do not directly measure actual costs, but only estimates of costs by bidders willing to do individual jobs. This level of cost, however, is most directly related to what individual landowners would pay. Before collecting and analyzing this information, an intensive examination of previous studies suggested problems and factors to consider.

Methods of cost analysis

As with output prices, a number of aspects of cost analysis affect the accuracy of estimation and the range of usefulness of the results. The following aspects affected the approach in this study:

Included components. Cost estimates should include all marginal or incremental costs--those costs not incurred if the

practices are not performed. In addition to wages, direct labor cost should include social security taxes, workmen's compensation, unemployment insurance, and allowances for leave time if any. Equipment cost should include depreciation and average maintenance costs. Marginal planning, inspection, and administrative costs should also be included. Previous treatments of overhead in timber growing cost studies have varied from full inclusion of all costs (Wikstorm and Alley, 1967) to nearly none (Manthy, 1970).

Separation of physical and price components. Methods that estimate input requirements for labor and equipment in physical units for each output unit are highly advantageous, since differences in the labor and equipment costs between regions and organizations and over time can be used to improve the accuracy of cost estimations for particular projects. Dollar costs of production are determined by multiplying inputs by appropriate wage rates, machine rates, and material costs. The sum of costs divided by the number of production units give average unit costs (Barraclough and Gould, 1955; Worley, et. al., 1965).

Equation models and variables. Different equations or models have been used in the three previous regression analyses of data from indiviudal projects. In models of Hilliker, Webster, and Tritch (1969) and in Conkin (1971) dependent variables were expressed (a) in physical units, either labor or equipment time required, and (b) on a per acre basis. In Wikstrom and Alley's (1967) model for dependent variable was combined dollar cost

of both labor and equipment expressed as the total cost of the project.

For each practice or group of practices they studied, Hilliker, Webster, and Tritch (1969) chose a priori the most significant single variable influencing cost. For hand planting and pulling, and machine site preparation practices they devised an arbitrary index scale of difficulty for the independent variable. For other practices they used quantified measures. The variables used are shown in table 7.1.

Wikstrom and Alley (1967) specified a more elaborate model than other studies. They included area as an independent variable in each equation in addition to one or more following additional discrete or continuous variables.

Discrete	Continuous
Species	Area
Finance class	Planting density
Brush cover	Total trees planted
Down material (slash)	Transportation

Their more elaborate regression model determined effects of area, number of trees planted, and brush cover density on total planting costs. Since the dependent variable was total cost, instead of per acre costs, the reduction of variance was quite high--85 percent or higher. The results are summarized in table 7.1.

Conkin's recent study (1971) included additional refinements. Total area of project was linearly related to cost for each practice. Conk n also found that average ground slope was significantly

Table 7.1--Factors found to significantly affect costs of timber growing practices 1/

	Yoho, Dutrow, and Moak (1969)	Hilliker, Webster and Tritch (1969)	Wikstrom and Alley (1967)	Conkin 2/ (1971)
Controlled burning	Average, less difficult and more difficult		A	
Site preparation-cutover stands	Average, less difficult and more difficult	Size and type of ground vegetation 3/	Area, accessibility area	Area, slope 3/ type of operation accessibility
Site preparation-partially harvested stands	Average, less difficult and more difficult	--	--	
Hand planting	Open or cutover land, number of trees	Extent of site preparation 3/	Area, trees per acre acre	Area, slope 3/ trees per acre, ground cover 3/ type of operation 3/
Machine planting	Open or cutover land, number of trees	--	--	
Cull tree removal by cutting	Average, less difficult and more difficult	Basal area removed	--	
Cull tree removal by chemical	Over or under 12" dbh trees per acre	Basal area removed		Area, accessibility, crew size, type of equipmemt 3/
Cull tree removal by girdling	Over or under 12" dbh	Basal area removed		

(continued)

Table 7.1--Factors found to significantly affect costs of timber growing practices 2/ (Continued)

	Yoho, Dutrow, and Moak (1969)	Hilliker, Webster and Tritch (1969)	Wikstrom and Alley (1967)	Conkin 2/ (1971)
Thinning	--	--	Area, accessibility	
Blister rust control	--	Number Ribes plants per acre	--	

1/ No factors were found significant for timber cruising (YDM), tree marking (YDM), Fire Protection (YDM,C), Weevil control (HWT), aerial operations (HWT) and stand conversion (C).

2/ Factors found significant in either labor or machine requirement regressions.

3/ Index constructed for these variables.

related to costs of planting and site preparation, accessibility to site preparation and cull tree removal, trees planted per acre and an index of ground cover to planting. Type of operation of equipment influences costs of site preparation, planting, and cull tree removal.

An additional problem all three studies encountered was that factors such as type of ground vegetation or equipment were not continuous variables. Indexes using categories in order of difficulty were not satisfactory. With three or more categories such an index implies the unlikely assumption that differences between each consecutive pair of categories are the same. A better method employs 0-1 dummy variables for each category.

Observation weighting. Most forest managers think of costs in dollar per acre. Use of per acre data in regression analysis, however, may not be statistically sound. If the observations in the regression are not weighted, small projects have the same weight as those for large projects, ignoring the fact that relative variance for small projects is likely to be much smaller than for large projects. Conkin (1971) recognized this fact and weighted his observations by the number of acres in each project. This is similar to using total cost for the entire tract or project, but does not allow for estimating a fixed cost per tract or the effect of number of tracts.

Analysis of Forest Service silvicultural contracts

The source of data used to help determined current cost

patterns for this study--silvicultural services contracts let by National Forest--proved an extensive source of information on timber growing costs.

The advantages of using data from silvicultural service contracts for determining costs of timber growing operations were: (a) The work from July 1, 1969 to June 30, 1970 covered almost 500,000 acres, a large fraction of all timber growing work done that year in the U.S., (b) information was available on many contracts of various practices and methods and in a number of forest types in the United States, (c) contract operations would be the cheapest and most practical means of accomplishing timber growing work by small and medium sized forest owners, who generally cannot do the work themselves nor form their own crews, (d) sufficient information is available for each contract to measure effects of project size and other factors. Direct overhead costs could be estimated. The data could also be obtained with reasonable costs.

Silvicultural service contracts are one of three means the Forest Service uses to accomplish timber growing operations on National Forests. The other two methods are fulltime reforestation and timber stand improvement crews, and Forest Service fire prevention and control, recreation, or timber sale crews who work on reforestation and timber stand improvement projects in slack periods when they are not engaged in their usual work. Though the Forest Service has not analyzed the relative costs of the three means to get the work done, it is widely believed

that contracting is less expensive per unit of output when either full-time silvicultural crews and quite a bit cheaper than fire, recreation, or timber crews.

Costs obtained from silvicultural contracts differ in an important respect from the cost information used in previous studies. The costs are not total costs or direct labor, equipment and material costs, but are contractor's estimates of their likely costs plus their allowances for risk and profit. When bids are numerous, competition tends to reduce or eliminate excess profits.

Several features of the contracting procedure limit the variation in bid prices accepted. First, forest supervisors are not apt to approve projects which appear to be unreasonably costly if they are small or unusually difficult. Second, when the bids are received the contracting officer cannot exceed the authorized total cost limit set by the supervisor or his staff. If no bid received is less than the authorized limit, all bids are rejected and the project is abandoned or readvertised. Third, unreasonably low bids are usually investigated to make sure the bidder (or the invitation for bids and the prospectus) has not erred and the bidder understands the project.

Data collection procedures. Data collection forms and instructions were sent to one National Forest in each of the Forest Service regions for trial collection of data. Comments on the form and instructions were made by the pilot National

Forests, Regional timber management staffs, and Washington Office Divisions. Final forms were sent to all Regions for distribution to all National Forests. Because the difficulty of partial sampling appeared to outweigh the cost of complete enumeration, the study included all silvicultural contracts throughout the continental United States.

Forms were edited, coded, and classified by predominant practice and method. Ambiguous responses concerning forest type, practice, method, or other information were resolved by judgment or reference to the source. Contracts with substantial expenditures in more than one major practice were not included in the analysis. Number of contracts for each practice and forest type are shown in table 7.2.

Computed total contract costs include contract award values and other Forest Service costs--material and equipment provided plus Ranger District administration. The latter costs were estimated from District man-hours spent on contracts multiplied by the total direct hourly cost for the average Ranger District professional and sub-professional employee ($5.10). Within forest types, standard deviations of the average cost for each practice and method were computed by using the ratio estimate technique. The coefficient of variation was used to select the significant cost information.

Regression analysis was possible for 773 of the 1,019 contracts let in FY 1970 within five types of treatment--slash disposal, site preparation, planting, thinning, and helicopter operations.

Table 7.2--Number of silvicultural service contracts by practice and forest type - FY 1970

	I	Site prep.	Planting	Seeding	Release	Precom. thinning	Animal control	Ferti-lization	Total
White-Red-Jack pine	I	2	5	--	--	--	--	--	7
Spruce fir	I	1	--	--	--	--	--	--	1
Longleaf slash pine	I	3	2	--	1	--	--	1	7
Loblolly shortleaf pine	I	16	8	1	--	1	--	--	26
Oak-pine	I	8	4	--	13	--	--	--	25
Oak-hickory	I	11	6	1	4	2	--	--	24
Maple-Beech-Birch	I	11	2	--	1	8	--	--	22
Aspen-Birch	I	19	11	--	1	--	--	--	31
Nonstocked (Eastern)	I	7	18	5	--	--	--	--	30
Douglas-fir	I	82	137	4	24	57	--	3	307
Ponderosa	I	78	50	1	4	136	3	--	272
Western white pine	I	16	19	--	--	2	--	--	37
Fir spruce	I	27	42	1	2	5	--	--	77
Hemlock-Sitka-Spruce	I	7	1	2	--	--	--	--	10
Larch	I	33	10	1	--	13	--	--	57
Lodgepole pine	I	29	4	1	1	38	--	--	71
Western hardwoods	I	--	1	--	--	--	--	--	1
Nonstocked (Western)	I	1	13	--	--	--	1	--	15
Total	I	350	335	17	51	260	4	4	1,019

Regression model. The regression analysis form used is patterned after the model developed in Chapter 3. This general model assumes that total cost (TC) of each treatment type, X_j, is the sum of a fixed factor for the contract and a variable cost per acre (VC_j) times the total acreage (A) involved in the contract. This concept is shown in the top chart in figure 7.1, and corresponds to equation (3.19):

$$TC_j = FC_j + VC_j * A$$

The fixed cost appears to be largely a function of a constant and a factor for the number of tracts in the contract, assuming that a project spread over a number of tracts would not be as efficient as a contract for the same acreage in one piece. For most treatments, the variable cost is influence by several to many factors. These are indicated by CV_jp in the model, with p = 1, 2,...njp for each j treatment type. Thus the entire equation for costs of treatments (3.20) is:

$$TC_j = f(NT) + A * f(XL_j, CV_{j1}, CV_{j2}, \ldots CV_{jp}, \ldots CV_{njp}) + e[E(\sigma_c)]$$

To transform this implicit function into a form of regression equation suitable for the analysis of the cost information, the manner in which each variable affects the cost must be hypothesized. The best form for the fixed cost factor appeared to be:

$$FC_j = b_{jf} + b_{jt} * (NT - 1) \qquad (7.1)$$

The most appropriate form for the variable cost component was:

$$VC_j = b_{ja} + b_{j1} * CV_{j1} + b_{j2} * CV_{j2} \ldots b_{jp} * CV_{jp} \ldots$$

$$+ b_{jnp} * CV_{jnp} \qquad (7.2)$$

The entire model of the regression equation would be:

$$TC_j = b_{jf} + b_{jt} * (NT - 1) + b_{ja} * A + \sum_{p=1}^{njp} (b_{jp} * CV_{jp} * A) \qquad (7.3)$$

Preliminary analysis, together with the survey of literature, suggested the following factors as most likely to have major significance on variable costs:

BC = Basic variable cost for each practice, method, forest type combination (or b_{vcb}).

A/NT = Acreage per tract included in the contract, since the size of tract may also influence variable cost.

$TYPE_i$ = 10 dummy variables codes for forest type.

WAGE = Index of hourly agricultural wages by State.

BIDS = Number of bids submitted.

$DIST_i$ = 3 distance codes in dummy variable form. A code indicating the relative accessibility on the job.

TUFF = 6 codes for presence of terrain factors in dummy variable form. These are types of obstacles thought to significantly affect cost.

$SEAS_i$ = 4 dummy variable codes for season of the year.

For planting and thinning contracts, the following additional variables and combinations of variables might also have influenced variable cost per acre:

TREES = Number of seedlings planted (in hundreds) or

number of trees per acre thinned (in hundreds).

TREES = TREES * TREES, since the effect of number of trees might not be linear.

SIZE = Age of seedlings planted in years, indicating size, or average diameter of trees thinned.

SIZE = SIZE * SIZE, since the effect of size may not be linear.

DINCH = 3.1414 * SIZE * TREES, since the sum of the circumferences of trees treated has frequently been found significant.

DAYS = Length of permissible planting season in days

For slash disposal contracts, additional dummy variables separated the methods.

METH = Code for method: 0 = lopping contracts
1 = piling contracts

In a regression analysis are 37 variables in addition to the constant. For each group of contracts, the average values and the coefficients of variation appear in table 7.3. In all of the groups of contracts some of the variables had a constant value. If, for example, no contracts were reported from a forest type, that variable would b 0 for all contacts and was omitted in a specific analysis. In addition, three sets of variables were mutally exclusive. Each contract had to have 1 of 3 distance codes, 1 of 4 season codes, and 1 of 11 forest type codes. Therefore, in each set one variable was omitted, usually the most numerous variable in each set. The largest number of variables included a regression equation was 30 in the analysis of hand planting costs.

Table 7.3--Means and coefficients of variation of cost regression variables

Variable	Observation group: Slash disposal Mean	Slash disposal CV	Site preparation Mean	Site preparation CV	Hand planting Mean	Hand planting CV	Powersaw thinning Mean	Powersaw thinning CV	Helicopter operations Mean	Helicopter operations CV
Fixed cost (constant)	1.000	.0	1.000	0	1.000	0	1.000	0	1.000	0
No. tracts	1.857	1.5	6.036	1.5	6.606	1.6	3.256	1.4	15.314	1.4
Area	159.918	.9	278.009	1.3	315.366	1.2	226.865	1.0	1555.627	2.3
Area^2	439.498	1.8	2097.895	3.2	2482.931	2.9	1038.651	2.5	154223.848	5.8
Area/tract	102.125	1.4	76.792		92.136	2.8	236.211	4.1	354.575	-
Method	.538	1.5							.318	7.1
Bids	1.896	1.1	2.428	1.8	2.354	1.5	2.315	1.1	1.862	2.5
No. trees/100					4.249	1.2	29.847	2.0		
Size or age					20.124	1.2	3.857	1.1		
Size x number					26.947	1.1	292.514	1.5		
(No. trees/100)^2					19.256	1.2	10594.903	-		
Size^2 or age^2					4.300	1.3	18.271	2.0		
Basal area							192.624	1.4		
Distance: 1/2 hr.			.060	4.0	.022	9.4	.055	7.2		
Distance: 1/2 to 1 hr	.234	2.7	.390	2.3	.341	2.5	.431	2.1		
Distance: 1 hr.	.766	1.1	.550	2.2	.637	1.7	.514	1.5		
Terrain: Slope			.054	7.1	.034	5.2	.144	4.4		
Rocks					.107	5.2	.047	5.7		
Snags	.080	3.6	.028	5.0	.076	3.2	.053	6.1		
Slash	.106	3.9	.147	3.4			.022	9.5		
Brush	.060	5.8	.075	5.2	.138	4.2				
Other	.285	2.7	.158	2.9	.182	3.7	.117	3.9		
Season: Winter					.158	4.3	.007	7.2	.011	5.0
Spring			.021	5.4	.477	2.4	.092	4.1	.226	2.8
Summer	.895	1.0	.745	1.7	.102	4.0	.715	1.5	.537	4.2
Fall	.088	2.8	.209	3.3	.260	3.0	.182	2.4	.204	2.9

(Continued)

Table 7.3--Means and coefficients of variation of cost regression variables (Continued)

Variable	Observation group: Slash disposal Mean	Slash disposal CV	Site preparation Mean	Site preparation CV	Hand planting Mean	Hand planting CV	Powersaw thinning Mean	Powersaw thinning CV	Helicopter operations Mean	Helicopter operations CV
Planting days	.				53.244	1.8				
Douglas-fir	.343	2.1	.085	.9	.558	2.0	.162	2.4		
Ponderosa pine	.025	4.3	.208	2.3	.130	3.7	4.849	1.4		
Western white pine	.270	2.6			.033	5.0				
Fir-spruce	.090	3.7	.109	7.7	.107	3.9	.008	14.7		
Larch	.129	3.2	.254	3.6	.029	5.8	.010	6.1		
Lodgepole pine	.222	2.7	.132	5.2			.090	3.3		
Northern			.187	2.7	.027	3.8				
Southern					.033	10.7				
Nonstocked West					.082	6.6				
Cost (dependent)	29.206	.9	38.648	1.2	36.398	1.0	23.421	.7	7.623	1.6

Distribution of variation

Scatter diagrams of both total cost and average per acre costs showed greater deviations around the probable trend line for large contracts than for small contracts. But on an average cost basis the deviations for small contracts were larger than for large contracts. The patterns suggested that the standard error might be related to a function of acreage or of total cost.

Thus, regressions were solved by two types of weighting. First, the weighting that seemed most appropriate from scattered diagrams--acres^2--was used. The variables, their coefficients, and associated t-test values appear in table 7.4. The regression program described in Chapter 4 introduced the variables into the equation in step-wise fashion. The general criteria for inclusion was whether the probability of significance of the coefficient (from 0) was greater than .90.

Secondly, the regresssions were solved by the iterative weighting procedures mentioned in Chapter 4. The resulting variables, their coefficients, and associated t-test values appear in table 7.5. The same criteria for inclusion were used.

In solving the regression analyses, correlations between independent variables proved to be a major problem in selecting the best set of variables for each regression. In many cases a high proportion of observations in one season, terrain class, or distance class were in one timber type. It was impossible to determine whether differences were due to the factor of the timber type. Such intercorrelations caused some coefficients to be illogical. Several variables, particularly average wage

Table 7.4--Regression coefficients for solutions obtained by weighting by area[2]

Variable	Slash disposal		Site preparation		Hand planting		Powersaw thinning		Helicopter operations	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Fixed cost	68.278	2.0	33.250	0.8	49.833	1.7	371.615	5.6	719.494	6.7
No. tracts			170.870	3.5	39.288	1.7			-164.425	-2.5
Area	43.322	13.5	36.338	13.1	42.912	11.1	20.760	7.6	14.432	7.6
Area^2					-0.587	-3.7	-1.367	-2.4		
Area/tract	-0.051	-2.4							-0.003	-1.6
Method	-19.010	-6.3								
Size or age					-1.323	-4.1				
(No. trees/100)^2					-0.469	-3.4				
Size * trees					1.190	5.7				
Distance: 1/2 hr.							-11.722	-2.2		
Distance:			-11.026	-3.6						
Terrain: Slope			11.756	1.6			8.404	2.2		
Other			6.35	1.8	3.189	2.0				
Season: Winter							-15.892	-2.0		
Summer							5.867	2.4	-4.387	-2.0
Fall	5.780	1.5								
Douglas-fir			19.083	4.7			13.681	4.8		
Ponderosa pine			6.336	2.0						
Fir-spruce	12.613	2.9			8.302	4.6				
Larch							10.218	1.6		
Lodgepole pine							9.083	2.5		
Northern					10.603	-4.3				
Southern					13.972	-3.7				
R^2	.838		.911		.937		.672		.637	

Table 7.5--Regression coefficients for solutions obtained by iterative weighting

Variable	Slash disposal		Site preparation		Hand planting		Powersaw thinning		Helicopter operations	
	Coef.	t	Coef.	t	Coef.	t	Coef.	t	Coef.	t
Fixed cost	172.816	1.7	542.262	2.6	84.702	2.3	494.114	5.0	2053.462	2.5
No. tracts			157.827	2.9						
Area	44.506	14.9	30.938	10.4	38.511	10.6	17.768	12.3	7.458	12.1
$Area^2$					-0.357	-3.1			-0.007	-3.1
Area/tract	0.037				-0.011	-2.0	-0.008	-4.1	-0.001	-3.7
Method	-18.648	-9.8								
Size or age					-0.910	-3.2				
$(No. trees/100)^2$					-0.278	-2.6				
Size * trees					0.933	5.3				
Distance: < 1/2 hr.							-7.670	-3.7		
Distance: >			-8.117	-3.4						
Terrain: Snags	7.308	2.0								
Season: Summer			5.517	2.3			3.692	2.4		
Douglas-fir	-5.677	-2.8	11.019	2.4			13.982	5.8		
Ponderosa pine			4.696	1.8	2.690	1.8				
Western white pine	-3.954	-1.9								
Fir-spruce					8.135	4.1				
Larch							19.778	2.4		
Lodgepole pine							13.464	4.1		
Northern					-11.391	-5.8				
Southern					-13.952	-6.6				
R^2	.875		.852		.935		.711		.958	

rate and number of bids, proved unuseable for this reason.

The variables that were finally included in the regression equation are considerably fewer than those significant in a strict statistical estimation. Variables for causal factors were allowed to enter the equation only if they were significant in the same direction with and without the presence of variables for forest types. Though intentionally selecting such variables reduced the variation "accounted for", the consistency and usability of the results were increased.

It is difficult to determine which equation solution technique is preferable. On balance the iterative solutions seemed to estimate the constant cost most consistently.

Factors causing cost differences

Significant results from individual factors that could be directly used in TIMSIM simulations were:

Total acreage. Size of jobs ranged from 7 to nearly 2,000 acres, with high proportions of the contracts between 100 and 300 acres. There were also a number of planting and thinning contracts under 100 acres.

The effect of total acreage on costs per acre was brought out by including (a) fixed cost per contract (as a constant) and (b) the square of acres in the regression equation of total cost.

In the final equations, estimated fixed cost per contract were significant in all five groups, and varied between $85 for hand planting and $2050 for helicopter operations. The size of fixed cost appears to be directly related to the degree of mechanization. The probability that a positive fixed cost was present is extremely high, though estimates of the range of fixed costs had high standard errors.

Number of tracts and average size.--Many of the silvicultural contracts for jobs of all practices and methods included separate tracts of land in the same contract. Using one contract for several tracts cuts the cost of Forest Service planning, administration, and inspection, and also costs of contractors. This presumably would lower the bids. The contracts which covered a number of tracts were generally for large total acreages.

The analysis included the number of separate tracts covered by the contract in two ways: (a) by estimating a fixed cost per additional tract, and (b) by including a variable of average acreage per tract as a factor influencing variable per acre cost. The results of the analyses showed that either one factor or another was moderately significant.

Effects of average area per tract, however, are not large. In general, extra tracts markedly reduce cost savings of large total acreages.

Number and age of trees planted--Hand planting contracts varied considerably in number of seedlings planted per acre and age of seedlings. Several combinations of number and size

of seedlings were included in the analysis, as mentioned in the regression model.

The most significant factors were both number of seedlings, age of seedlings and age of seedlings times number of seedlings. As might be expected costs increase with the number and age of seedlings. Though the seedlings were supplied by the Forest Service, their cost was included in the total cost of the contracted job.

Number and diameter of trees thinned--The range in number of trees thinned per acre varied from 100 per acre or less to over 10,000 very small trees, and tree diameters ranged from 1 to 8 inches. The range in estimates of number of trees may include some overestimates since the number of trees is often not estimated in preparation of the contracts and had to be estimated later. The model included seven measures of the number, diameter, and basal area of trees cut. None of the variables were consistently significant.

Forest type--Much of the variation in average costs per acre shown in table 7.3 is associated with job intensity and difficulty factors discussed. Even after this variation had been removed, however, it appeared that unspecified factors associated with forest types had a major influence on cost. Thus 1-0 variables for each major forest type were included in a final stage. Since each contract had to be in one forest type or another, the most common type was not given a variable and is considered the base. These are indicated with 0's. Forest type was not thought to be significant for helicopter operations.

Eleven of these variables were significant among the 5 regressions.

Variation not accounted for

Since the analyses estimated total costs rather than average costs, the regressions accounted for a high proportion of the variation. The cost factors included removed from 71 to 94 percent of the variation. Unexplained variation, though substantially reduced, is still large. But it is unlikely that further combinations of cost variables already used would substantially reduce the remaining variation.

Wide variation in these costs are not surprising. These contracts were not controlled laboratory of experimental trials under uniform conditions. As operational jobs, a wide variety of uncontrollable and perhaps nonmeasurable circumstances affected the total cost. Some of the more important factors may have been a wide variety of terrain and expected bad weather conditions. Among such factors likely to be are: Difficult access to job during the season work must be performed; slash, debris, brush, rocks, and hard soil that would slow workers; density and limbiness of timber in thinning operations; and perhaps variations in standards expected of the work. Few ways to include such factors other than the variables already incorporated are apparent.

The procedure described in Chapter 4 permitted analyzing the pattern of variance encountered in the regression analysis of Forest Service contract costs. The residuals were fitted by secondary regression to the equation.

Treatment costs used

The foregoing analysis demonstrated that fixed costs per tract are significant in the cost structure of timber growing treatments, and that the pattern of variance of costs follows the pattern anticipated.

The information used as a data base in the previous sections did not include, however, a sufficient number of contracts from the southern pine area to provide unbiased direct estimates of costs for local conditions.

The approach that this study takes is to apply the information from the national cost patterns to more specific cost data gathered from a wide variety of sources in the South. The data from these sources were not suitable for statistical analysis, but nevertheless are felt to be representative.

The best compilation of these costs appears in an unpublished report prepared by McClay (1969) for the Forest Service's new Outlook for Timber in the United States (1973). McClay, on the basis of literature and extensive contacts with Forest Service, estimated average costs for large tracts and the principal factors which affect them. These data were combined with that produced by the previous regression analysis to produce the cost estimating functions for simulation in this study.

The functions follow the form required by the TIMSIM cost subroutine. The cost function in TIMSIM estimates costs by the following modification of equation (7.3).

$$TC_j = FC_j + A * (b_{j0} + b_{j1} * CV_{j1} + b_{j2} * CV_{j2}) \qquad (7.4)$$

Table 7.7 shows the values for FC_j, b_{j0}, b_{j1}, and b_{j2}.

Table 7.7--Cost coefficients for treatments simulated in this study

Treatment	Fixed cost (FCOST)	Per acre cost ($VCOST_0$)	Factor cost ($NCOST_1$)	Factor 1/ 1	Factor cost^2 ($VCOST_2$)	Factor 1/ 2
Type conversion	800.	11.00	.200	B	-	
Site preparation	540.	5.00	5.000	F	-	
Hand planting	80.	-	5.000	F	.030	N
Machine planting	300.	-	8.00	F	.010	N
Hardwood spraying	400.	12.00	-		-	
Precommercial thinning	460.	6.00	-		-	
Cull tree removal	120.	3.00	.010	D*N	-	
Prescribed burning	50.	1.25	-		-	
Timber marking	50.	.75	.002	D*N	-	
Annual management	8	-.04	.250	F	-	
Property taxes	8.	-.29	.0125	SI	-	

1/ B = Basal area; F = site factor for each treatment, D = diameter, N = number of trees, SI = site index.

A basic consideration in deterining the fixed cost is the degree of mechanization and the difficulty in moving equipment from tract to tract. Those that have large fixed costs require either crawler or heavy wheeled tractors. Hardwood spraying can be done from tractor to airplane mounted sprayers.

The variable costs are based on the following factors:

Type conversion is commonly applied to destroy woody vegetation on areas dominated by deteriorated hardwood stands or brush. Operations usually require shearing blades, choppers, crushers, or chains mounted on heavy crawler tractors, sometimes in combination with prescribed fire or application of chemicals. The land is prepared for planting of pine seedlings, though the planting cost is separately estimated. Basal area of the stand removed influences costs more than any other factor. Cost estimated by the equation are shown in table 7.8.

Site preparation removes slash, small hardwoods, and brush after regeneration harvest of a merchantable stand. The bare seedbed exposed increases the probability of successful natural regeneration, or survival of planted seedlings. Cost is dependent on how much material is left after the harvest cut and how much undesirable vegetation was present before harvest. Since the variable factors are numerous, levels of difficulty (F) have been defined. The specific levels associated with each opportunity will be discussed in Chapter 10. Estimated costs appear in table 7.9.

Hand and machine planting. Seedlings can be planted with equal success by hand, using a planting bar or mattock, or by a tractor-drawn tree planter. Each has a different cost structure, with hand

Table 7.8--Type conversion costs per acre

Tract size	Basal area 20.	40.	60.	80.	100.
(Acres)	(Dollars per acre)				
10.	95.00	99.00	103.00	107.00	111.00
20.	55.00	59.00	63.00	67.00	71.00
40.	35.00	39.00	43.00	47.00	51.00
80.	25.00	29.00	33.00	37.00	41.00
160.	20.00	24.00	28.00	32.00	36.00
320.	17.50	21.50	25.50	29.50	33.50
640.	16.25	20.25	24.25	28.25	32.25
1280.	15.62	19.62	23.62	27.62	31.62
2560.	15.31	19.31	23.31	27.31	31.31

Table 7.9--Site preparation costs per acre

Tract size	Cost level 1.	2.	3.	4.
(Acres)	(Dollars per acre)			
10.	64.00	69.00	74.00	79.00
20.	37.00	42.00	47.00	52.00
40.	23.50	28.50	33.50	38.50
80.	16.75	21.75	26.75	31.75
160.	13.38	18.38	23.38	28.38
320.	11.69	16.69	21.69	26.69
640.	10.84	15.84	20.84	25.84
1280.	10.42	15.42	20.42	25.42
2560.	10.21	15.21	20.21	25.21

planting being cheaper on small tracts and under difficult planting conditions caused by slash and brush. The cost routine computes the cost for both hand and machine planting, and selects the lowest-cost method for the simulation. The principal factors are a site difficulty factor (F) and the number of trees planted per acre. Table 7.10 shows the lowest cost for either hand or machine planting for each combination of site factor, seedlings per acre, and tract size. Above the dotted line the costs are for hand planting, and below for machine planting.

Hardwood spraying. The technology of spraying hardwoods with herbicides has changed rapidly in recent years, so little has been published on treatment cost. No variable factors related to conditions appear significantly related to costs. The assumed costs appear in table 7.11.

Precommercial thinning. In the South, the most prevalent means of reducing stocking of young stands is to disk or chop strips at 90 degree angles through the tract. This leaves small islands of undisturbed seedlings. The technique is relatively insensitive to site factors if the site has been prepared at time of regeneration. The costs for various sized tracts are shown in table 7.12.

Cull tree removal. Cull tree removal is usually accomplished by injecting a concentrated herbicide into the base of a large hardwood tree, or a herbicide spray on the base of small trees. The most pertinent variable factor is the sum of diameters of the trees treated, directly proportional to their circumference. Table 7.13 shows the estimated costs.

Controlled burning. The ground cover underneath established stands

Table 7.10--Planting costs per acre

Tract size	Number of trees				
	350.	500.	650.	800.	1000.
(Acres)	(Dollars per acre)				
	Site factor = 1.				
10.	23.50	28.00	32.50	37.00	43.00
20.	19.50	24.00	28.50	31.00	33.00
40.	17.50	20.50	22.00	23.50	25.50
80.	15.25	16.75	18.25	19.75	21.75
160.	13.37	14.87	16.37	17.87	19.87
320.	12.44	13.94	15.44	16.94	18.94
640.	11.97	13.47	14.97	16.47	18.47
1280.	11.73	13.23	14.73	16.23	18.23
2560.	11.62	13.12	14.62	16.12	18.12
	Site factor = 2.				
10.	28.50	33.00	37.50	42.00	48.00
20.	24.50	29.00	33.50	38.00	41.00
40.	22.50	27.00	30.00	31.50	33.50
80.	21.50	24.75	26.25	27.75	29.75
160.	21.00	22.87	24.37	25.87	27.87
320.	20.44	21.94	23.44	24.94	26.94
640.	19.97	21.47	22.97	24.47	26.47
1280.	19.73	21.23	22.73	24.23	26.23
2560.	19.62	21.12	22.62	24.12	26.12
	Site factor = 3.				
10.	33.50	38.00	42.50	47.00	53.00
20.	29.50	34.00	38.50	43.00	49.00
40.	27.50	32.00	36.50	39.50	41.50
80.	26.50	31.00	34.25	35.75	37.75
160.	26.00	30.50	32.37	33.87	35.87
320.	25.75	29.94	31.44	32.94	34.94
640.	25.62	29.47	30.97	32.47	34.47
1280.	25.56	29.23	30.73	32.23	34.23
2560.	25.53	29.12	30.62	32.12	34.12

Table 7.11--Hardwood spraying costs per acre

Tract size	Spraying
(Acres)	(Dollars per acre)
10.	52.00
20.	32.00
40.	22.00
80.	17.00
160.	14.50
320.	13.25
640.	12.63
1280.	12.31
2560.	12.16

Table 7.12--Precommercial thinning costs per acre

Tract size	
(Acres)	(Dollars per acre)
10.	51.80
20.	28.80
40.	17.30
80.	11.55
160.	8.67
320.	7.24
640.	6.52
1280.	6.16
2560.	5.98

Table 7.13--Cull tree removal costs per acre

Tract size	Diameter (Inches) 250.	500.	750.	1000.	1250.	1500.
(Acres)	(Dollars per acre)					
10.	17.50	20.00	22.50	25.00	27.50	30.00
20.	11.50	14.00	16.50	19.00	21.50	24.00
40.	8.50	11.00	13.50	16.00	18.50	21.00
80.	7.00	9.50	12.00	14.50	17.00	19.50
160.	6.25	8.75	11.25	13.75	16.25	18.75
320.	5.87	8.37	10.87	13.37	15.87	18.37
640.	5.69	8.19	10.69	13.19	15.69	18.19
1280.	5.59	8.09	10.59	13.09	15.59	18.09
2560.	5.55	8.05	10.55	13.05	15.55	18.05

is frequently burned at 2-5 year intervals to kill small hardwood seedlings and sprouts, other brush, and reduce inflamable material, and consequently hazard from wildfire. No variable factor seems important in cost. Table 7.14 shows the expected cost per acre for various tract sizes.

Timber marking. Timber marking and sales preparation is required to mark timber and prepare either a sale or a cull tree removal contract. A fixed cost per acre represents the time necessary for a trained tree marker to walk through the tract, and additional time is needed to judge and mark either trees to cut or trees to leave. The variable factor most appropriate is the number of trees times diameter. Marking plantations is less expensive then natural stands because of increased uniformity and size of trees. The variable cost coefficient for plantations is .002 per diameter inch rather than .003. The estimated costs are shown in table 7.15.

Annual management. Annual management costs cited in the literature are quite diverse. This study assumes that the cost for planning and and administration is roughly proportional to the number and complexity of treatments, with factors ranging from 0 to 2. A relatively small fixed cost per tract was assumed. The estimated costs are shown in table 7.16.

Property taxes. Methods of assessment, tax rates, and consequent effective tax rates vary widely among states (Williams 1968) including those in the South. States have made numerous efforts to modify assessment guides, and property tax structures to relieve forest owners from the effects of continual taxes without income, and the taxes on the accumulating capital (Williams, Siegel 1969).

Table 7.14--Controlled burning costs per acre

Tract size	
(Acres)	(Dollars per acre)
10.	6.25
20.	3.75
40.	2.50
80.	1.88
160.	1.56
320.	1.41
640.	1.33
1280.	1.29
2560.	1.27

Table 7.15--Timber marking costs per acre

Tract size	Diameter (Inches) 250.	500.	750.	1000.	1250.	1500.
(Acres)	(Dollars per acre)					
	Cost factor = 2.					
10.	6.25	6.75	7.25	7.75	8.25	8.75
20.	3.75	4.25	4.75	5.25	5.75	6.25
40.	2.50	3.00	3.50	4.00	4.50	5.00
80.	1.87	2.37	2.87	3.37	3.87	4.37
160.	1.56	2.06	2.56	3.06	3.56	4.06
320.	1.41	1.91	2.41	2.91	3.41	3.91
640.	1.33	1.83	2.33	2.83	3.33	3.83
1280.	1.29	1.79	2.29	2.79	3.29	3.79
2560.	1.27	1.77	2.27	2.77	3.27	3.77
	Cost factor = 3.					
10.	6.50	7.25	8.00	8.75	9.50	10.25
20.	4.00	4.75	5.50	6.25	7.00	7.75
40.	2.75	3.50	4.25	5.00	5.75	6.50
80.	2.12	2.87	3.62	4.37	5.12	5.87
160.	1.81	2.56	3.31	4.06	4.81	5.56
320.	1.66	2.41	3.16	3.91	4.66	5.41
640.	1.58	2.33	3.08	3.83	4.58	5.33
1280.	1.54	2.29	3.04	3.79	4.54	5.29
2560.	1.52	2.27	3.02	3.77	4.52	5.27

Table 7.16--Management costs per acre

Tract size	Cost level 1.	2.	3.	4.
(Acres)	(Dollars per acre)			
10.	1.01	1.26	1.51	1.76
20.	0.61	0.86	1.11	1.36
40.	0.41	0.66	0.91	1.16
80.	0.31	0.56	0.81	1.06
160.	0.26	0.51	0.76	1.01
320.	0.23	0.48	0.73	0.98
640.	0.22	0.47	0.72	0.97
1280.	0.22	0.47	0.72	0.97
2560.	0.21	0.46	0.71	0.96

This study employs a relatively simple property tax provision. Annual tax rates per acre are based on generally prevalent levels in the South and recognize that land productivity and alternative land use affect them. The rates were $.50 for site 60, $.75 for site 80, ahd $1.00 for site 100 land per acre per year (table 7.17).

Variation in costs

The basis for the variation patterns is the analysis of the relation of regression residual to predicted cost for the entire tract. The variation was closely related to the relative size of the fixed cost. The assigned cost variation patterns for the costs in the simulation model are shown in table 7.18.

Trends in treatment costs

Other than the limited information on trends in costs uncovered in the surveys of industry costs (Yoho and Fish, 1961, Somberg, Eads, and Yoho, 1963; and Yoho, Dutrow, and Doak, 1969), there are no trend data for forest treatment costs. Yet most forest managers feel that costs are rising steadily and will continue to do so.

Cost experience in the last two decades (and that reported in the mentioned surveys) have been influenced by several factors that may not recur. Within this period the minimum wage has been raised from $.50 to $1.60 an hour. Though a large number of woods employees have remained under the agricultural worker exemption, the minimum wage increases have substantially affected rural wage patterns and have brought rural southern wages closer to the national average. Further increases in the minimum

Table 7.17--Property taxes per acre

Tract size	Site index 60.	80.	100.
(Acres)	(Dollars per acre)		
10.	1.26	1.51	1.76
20.	0.86	1.11	1.36
40.	0.66	0.91	1.16
80.	0.56	0.81	1.06
160.	0.51	0.76	1.01
320.	0.48	0.73	0.98
640.	0.47	0.72	0.97
1280.	0.47	0.72	0.97
2560.	0.46	0.71	0.96

Table 7.18.--Equation for estimating variation in costs in simulation model.

Cost type	Fixed cost	Equation
Type converstion	800	$ERR^2 = 2.00 * \hat{Y}^{1.5}$
Site preparation	540	$ERR^2 = .70 * \hat{Y}^{1.6}$
Machine planting	300	$ERR^2 = .10 * \hat{Y}^{1.8}$
Hand planting	80	$ERR^2 = .01 * \hat{Y}^{2.0}$
Hardwood spraying	400	$ERR^2 = .25 * \hat{Y}^{1.7}$
Precom. thinning	460	$ERR^2 = .25 * \hat{Y}^{1.7}$
Cull tree removal	120	$ERR^2 = .07 * \hat{Y}^{1.9}$
Controlled burning	50	$ERR^2 = .06 * \hat{Y}^{2.0}$
Timber marking	50	$ERR^2 = .02 * \hat{Y}^{2.0}$
Annual management	8	$ERR^2 = .04 * \hat{Y}^{2.0}$
Property taxes	8	$ERR^2 = .06 * \hat{Y}^{2.0}$

$$e^2 = a * Y^b$$

or: $$\log_{10}(e^2) = \log_{10}(a) + b * \log_{10}(Y) \qquad (7.5)$$

The patterns for the three most pertinent cost variation relationships are:

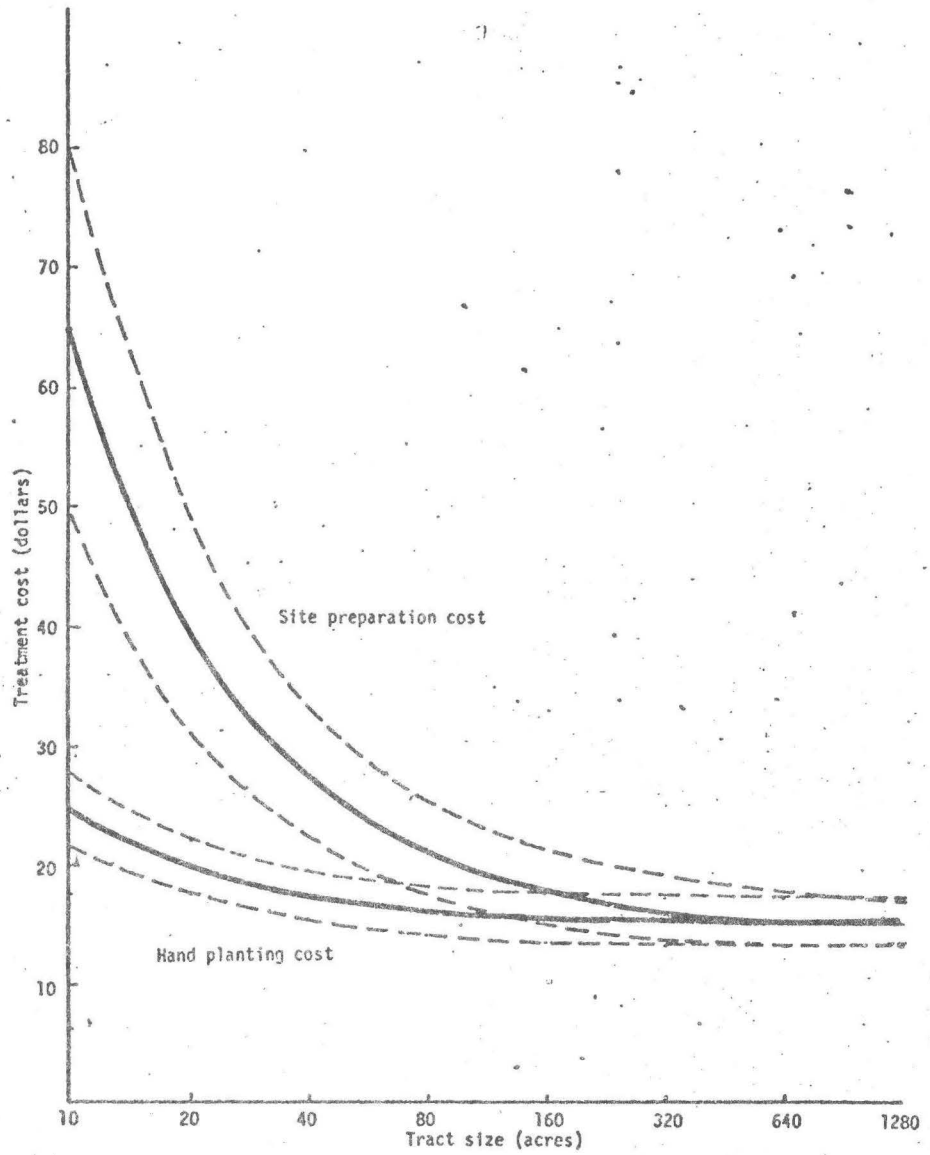
	Iterative	Fixed (area^2)
Site preparation	$e^2 = .7593 * Y^{1.6039}$	$e^2 = .5323 * Y^{1.6267}$
Thinning	$e^2 = .0780 * Y^{1.865}$	$e^2 = .2357 * Y^{1.7752}$
Hand planting	$e^2 = .0073 * Y^{2.0132}$	$e^2 = .0036 * Y^{2.0981}$

When the b exponent is 2.0 the standard error is proportional to expected cost and that proportion is the square root of the a coefficient. If the b coefficient is smaller than 2.0 the a coefficient must be relatively larger if the same proportion of SE to expected Y is to be the same at mean value.

To compare these patterns, confidence intervals of one standard error were computed for each of the above equations based on the iterative solutions. To make the comparisons more useful, the cost estimating equation employed was (3.19), where the variable cost was \$15, and the FCOST was \$500 for site preparation, \$300 for thinning, and \$100 for planting. The resulting cost patterns are shown in figure 7.1.

It is apparent that the variation pattern is closely related to the amount of fixed cost. Where fixed cost are high, the proportional variation for small projects is much higher than for large tracts. For types of operations with small fixed cost, the variation in costs is more closely proportional to expected costs, regardless of project size.

Figure 7.1--Pattern of costs per acre and variation for various fixed costs and tract sizes. Site preparation fixed cost is $500, hand planting $100.



wage may not have a similar effect.

Secondly, increases in the intensity of most treatments have tended to make them more costly in real terms than several decades ago. At that time many treatments now standard were in the experimental or trial stage of development.

Consequently, development of historical cost trends for forestry treatments was not considered. The nearest industry for which cost trends might be comparable is agriculture, and the relatively abundant data on long-term trends in labor, vehicles, and machinery are probably representative of the type of costs for timber growing treatments. Though they have been affected by minimum wages and by changes in technology, the influence of these factors are not predominant.

Trends in agricultural costs

Table 7.19 shows real cost patterns for three types of agricultural costs in the southern states covered by the study. All are on an index basis with 1967 = 100 and deflated by the all commodity wholesale price index. The three series were analysed by the same time trend equations as were used for timber and stumpage prices in Chapter 6. The forms were:

1. Linear time trends with the form:

$$C_j = a + b * T \qquad (7.6)$$

with the base year being 1900, or

2. Exponential time trends with the form:

$$C_j = a * b^T$$

or:

$$\log_{10}(C_j) = \log_{10}(a) + \log_{10}(b) * T \qquad (7.7)$$

Table 7.19 --Annual southern agricultural cost indexes (1967 = 100), 1910 - 1970, adjusted to constant dollars

Year	Wages	Vehicles	Machinery	Year	Wages	Vehicles	Machinery
1910	30.30		60.60	1940	37.03	81.48	81.48
1911	35.92		65.86	1941	39.91	77.60	75.38
1912	33.70		61.79	1942	45.18	72.69	68.76
1913	33.33		61.11	1943	58.16	73.17	69.41
1914	34.18		62.67	1944	70.89	78.35	70.89
1915	33.51		61.45	1945	76.92	80.58	69.59
1916	29.54		52.27	1946	73.83	72.23	62.60
1917	28.09		44.62	1947	64.05	67.97	58.82
1918	31.06		50.29	1948	62.80	70.04	62.80
1919	33.61		49.01	1949	64.80	81.32	73.69
1920	35.22		45.28	1950	61.12	78.23	73.34
1921	35.78		69.58	1951	60.37	75.74	71.35
1922	36.14		62.24	1952	66.59	81.26	75.62
1923	38.61		61.77	1953	69.79	81.23	76.65
1924	41.58	55.44	67.32	1954	68.49	81.05	77.62
1925	39.39	54.40	61.91	1955	69.47	82.00	77.44
1926	44.66	54.36	64.07	1956	69.45	81.58	78.28
1927	44.71	58.94	69.10	1957	70.73	84.67	79.31
1928	44.17	58.23	66.26	1958	71.88	87.73	81.39
1929	44.80	61.09	67.20	1959	75.94	89.66	85.44
1930	47.19	65.16	74.15	1960	77.97	88.51	86.40
1931	42.55	77.12	85.10	1961	80.42	88.88	88.88
1932	35.92	83.83	92.81	1962	82.27	91.77	90.71
1933	29.49	82.59	88.49	1963	84.65	95.23	93.12
1934	31.08	77.72	80.31	1964	86.58	96.09	95.03
1935	31.55	72.81	77.66	1965	86.34	93.37	92.36
1936	31.25	76.92	76.92	1966	93.18	96.19	96.19
1937	33.70	74.15	74.15	1967	100.00	100.00	100.00
1938	37.03	86.41	83.95	1968	105.36	102.43	102.43
1939	37.78	83.12	85.64	1969	111.73	102.34	103.28
				1970	115.94	103.26	105.07

The coefficients resulting from the regressions appear in table 7.20 together with the trend level estimates for 1970.

Based on the reduction of variance as measured by R_2 the equation that provides the best fit is the linear trend based on 1947-70 data. Labor wages have increased 2.1 percent a year, machinery 1.7 and vehicles 1.4. For much the same reasons as the similar series was chosen for projecting lumber prices, the linear trend was thought to be the best basis for projecting timber growing costs. This implies a larger proportional increase in the first few decades of the projection period than the last.

It was impractical, however, to estimate the proportion of the costs that are labor, machinery, and vehicles, and how the proportion might change in future decades. Thus an average rate of increase in costs was used for projection--1.8 percent of the base 1970 prices per year. The trend in the three price index series from 1947 to 1970, and projections for the next 40 years are shown in figure 7.2.

Summary

This chapter has reviewed the concepts of estimating costs for timber growing treatments, and has made an econometric analysis of contractural costs from silvicultural service contracts let by the Forest Service in the United States. From these contracts the hypothesis that fixed costs per project and per tract were statistically significant and that the standard errors of cost estimates increased less than proportionately with size of contract.

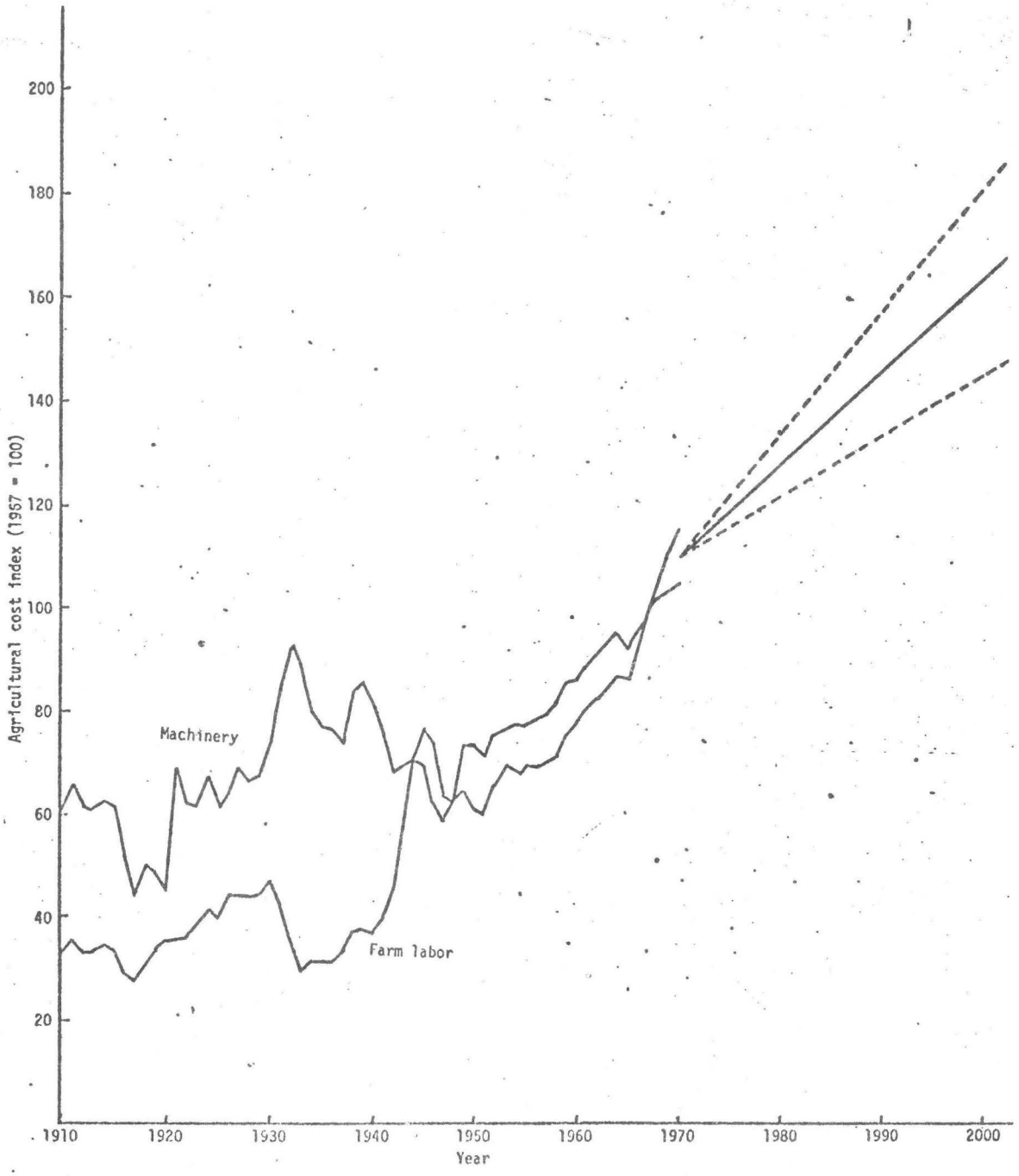
This information was combined with regional cost information

Table 7.20--Coefficients for trend regressions of agricultural costs, 1910 to 1970.

Regression	a coef.	b coef.	R^2	1970 Trend est.	Rate of increase
Constant real price increases					
1910-1970					
Labor	7.766	.1193	.812	.912	1.30
Vehicles[1/]	42.510	.797	.744	.983	.81
Machinery	49.254	.623	.610	.929	.67
1947-1970					
Labor	-45.516	2.131	.879	103.6	2.06
Vehicles	7.797	1.363	.946	103.2	1.32
Machinery	-17.764	1.746	.963	104.5	1.67
Proportional real price increases					
1910-1970					
Labor	- .34330	.00911	.827	95.9	2.12
Vehicles[1/]	- .68761	.00446	.722	100.0	1.07
Machinery	- .71492	.00373	.592	94.6	.85
1947-1970					
Labor	-.23026	.01129	.920	104.8	2.63
Vehicles	-.53955	.00683	.923	104.1	1.58
Machinery	-.38633	.00915	.944	106.4	9.44

1/Series for vehicles begins in 1924.

Figure 7.2--Trends in agricultural costs for hourly farm labor and machinery, 1910 to 1970, with projections to 2000 using the linear trend used in this study.



assembled for southern pine timber growing. The cost functions produced estimated costs for 11 types of timber growing treatments by size of tract, and for most treatments, by factors related to the difficulty of the work or site conditions.

Estimates of the rates by which these treatment costs may increase in the future are based on time trend analysis of agricultural costs for the southern United States.

Chapter 8

RISKS OF LOSS FROM FIRE, STORM, INSECTS & DISEASE

Losses from fire, storm, insects, and disease are among the most important factors affecting financial returns from timber growing. Despite the availability of information on causal factors and control measures feasible, seldom have studies been made of impact of losses on financial returns from individual stands. One exception is Flora.

Two types of losses must be considered. First are endemic losses that regularly affect single trees or portions of stands. The loss of an individual tree or small group of trees is minor and is soon undetectable. Though perhaps important in the aggregate, it is generally impractical to control or prevent most types of endemic losses. Growth and yield estimates developed in Chapter 5 are adjusted for them.

The second type of loss kills or reduces in value a major portion of the timber stand. These occur at infrequent and irregular intervals, but often destroy or degrade such a large proportion of the trees that yields are significantly reduced. Such losses affect selection of species to plant or favor in thinnings, timber growing schedules, and volume of harvest. These major losses will be discussed in this chapter.

For a given loss it is often difficult to assign a specific cause, since a number of agents may have been involved simultaneously or in sequence. Nevertheless, estimates of aggregate mortality from the major types of loss per acre of commercial forest land in the South for 1962 has been made as follows (USDA Forest Service, 1965):

Cause	Annual loss per acre in cubic feet		
	Total	Hardwoods	Softwoods
Fire	.5	.2	.3
Insects	.5	.1	.4
Disease	.3	.1	.2
Weather and animals	1.7	1.1	.6
Other	3.5	2.6	.9
Total	6.5	4.1	2.4
Percent of growth	17.4	27.0	10.6

In this study it will be possible to consider only five important types of loss and to construct initial probability statements for each.

Methods of estimating impacts

The usual approach for including losses in economic analyses of timber growing is to adjust harvest yields by estimated rates of loss throughout rotation (Water, 1969). Average rates of loss may tend to understate the impacts of losses on timber growing regimes and financial returns for several reasons. These agents cause declines in quality and growth rates that may make entire stands unmerchantable, losing more volume than directly affected. They may make some types of investment uneconomic.

An improved approach is permitted by stochastic simulation. Elaboration of simulation models can recognize the random nature of occurrence and severity of impact, interrelations between types of losses and possibilities for salvage or destroyed or injured timber.

Simulation of losses must consider several aspects, including

the following:

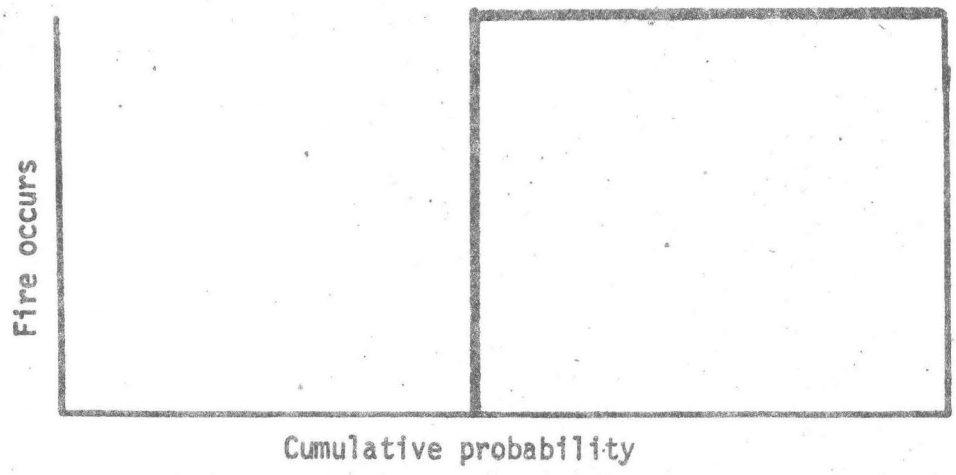
1. Probability that a loss will occur within a stand during a planning period. Tract size, stand age and density, and previous history of disturbance often influence the probability of occurrence. Chart A of figure 8.1 is a inverse cumulative probability function that a loss will occur in a tract. If a random probability is drawn greater than E, a loss occurs. The position of E is primarily dependent on size of area--the larger the area the more likely to be a loss. In the case of fire and other losses, length of tract perimeter is an important index of risk of fire occurrence or spread from another tract. The point E must be computed for each type of loss and stand condition.

2. Probability of size of area affected. Chart B of figure 8.1 shows the cumulative probability of size of area affected. This is based on statistics on size of fires and insect epidemics. In many types of losses, however, either the entire stand is affected or it is not. The size of area lost is usually influenced by stand attributes.

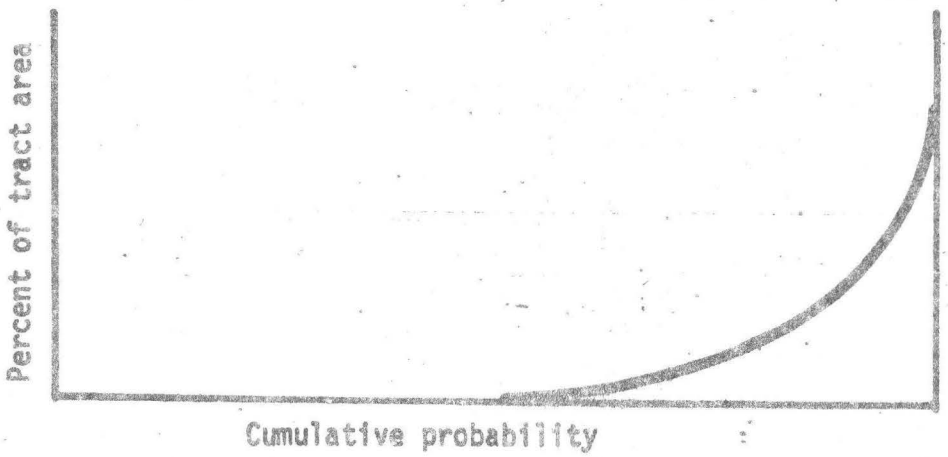
3. Probability of severity of damage once a portion of a stand is affected. Among the attributes for which change will be simulated are: (a) basal area of growing stock, (b) average diameter of trees,(c) quality of trees. Chart C shows the probability of basal area killed or so injured that it would die during the next planning period. As with occurrence and size of area affected, the portion of basal area affected is decided by a generated random number, and computing the cumulative probability associated with

Figure 8.1--Illustrative Probability distributions to simulating the impacts of losses from natural causes.

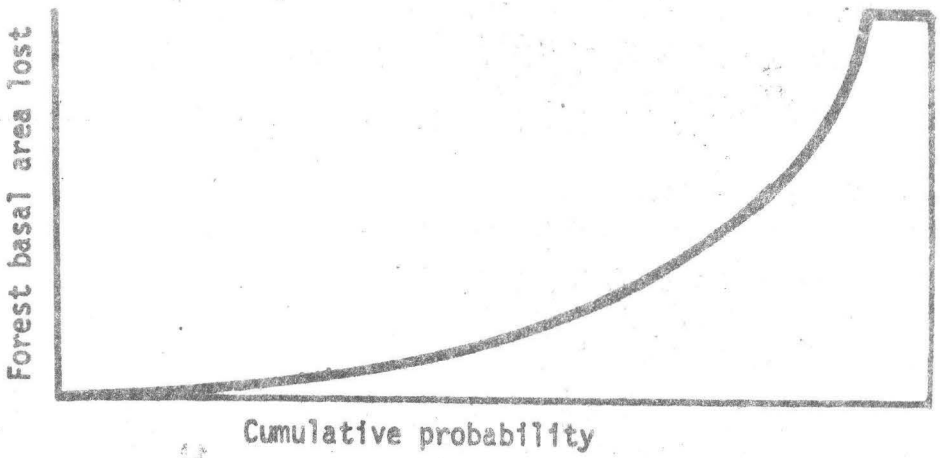
A. Probability of loss occurring in stand.



B. Probability of proportion of area affected.



C. Probability of basal area affected in loss area.



it. The effect on other attributes is often directly linked to basal area impact and type of loss. For some types of loss, the effect was assumed to be similar to that of thinning from below, in other cases it was assumed to be a proportional loss of trees or like a thinning from above.

4. Salvage value of timber killed or injured. Often this has substantial value mitigating the loss. In designing a routine to estimate salvage value, several alternatives were considered. The first alternative was to compute a simple proportional value. This would have overestimated salvage value of small losses and underestimated values of large losses. A second alternative, which was adopted, was to estimate unit prices (a) assuming that none of the timber had tree grades A or B, (b) an effective diameter of one half the actual diameter. This applied to a proportion of volume killed determined by type of loss. In this study it was assumed that if more than one half the volume of timber on a tract was killed, the entire tract was cut and the rotation started anew.

Information for deriving most functions for losses is lacking in adequate detail. Only general observations of the incidence of loss and degree of stand change is available for many aspects of loss. Much of the information concerning some types of loss comes from personal contacts with Forest Service researchers. But individual foresters or owners would not have, in general, more knowledge than this.

Wildfire losses

Despite organized forest fire protection in nearly all 800 forested counties in the South, wildfires are a major cause of loss. More than 98 percent of fires occurring in the South are man caused; the rest are lit chiefly by lightning strikes.[1/] Suppression of most fires is a relatively easy and routine operation. About 90 percent are put out when they are still smaller than 10 acres. In pine stands small fires, generally cause little damage, since only the undergrowth is burned and crowns of shorter trees scorched (Ryan, 1971).

The remaining 10 percent of the fires cause nearly all the economically significant damage. In Georgia, less than 1 percent of the fires between 1959 and 1968 were over 100 acres, but they burned more than 20 percent of the area and caused an even higher proportion of the damage.

The area burned in the South in the last five years, the average area protected (and to which the statistics apply), and the 5-year burn rate is shown in table 8.1. Occurrences of fire in pine forest types could not be separated from those on other forest types. Several variables are often used to measure relative severity of the fire situation, and will be useful in this study.

Fire occurrence. The fire occurrence rate (FOR) is:

$$FOR = \frac{F * 1{,}000{,}000}{A * T} \qquad (8\text{-}1)$$

1/The principal source of wildfire statistics is the annual compilations of the U.S. Forest Service (1972).

Table 8.1--Number of wild forest fires are area burned in the South from 1966 to 1970, and implied 5 year fire burn rates.

Year	Area protected	Number of fires	Area burned	Fire occurrence rate	Burned area rate
	(1,000,000) acres	(1000)	(1000) acres		
1966	198.0	58.5	1,174.5	.295.	5,932
1967	216.1	69.6	1,206.7	322.	5,584
1968	195.8	67.0	943.3	342.	4,818
1969	193.4	62.3	923.1	322.	4,773
1970	200.4	63.5	919.1	317.	4,586
Average	1003.7	320.8	5,166.7	320.	5,147

where F is number of fires, A is area protected and T the years covered. In counties within the South, FOR varies from about 100 to 500 and in some extreme cases to 1000 (Doolittle, 1969). As table 8.1 shows, the average rate from 1966 to 1970 was 320, with little indication of trend. In Georgia, a series from 1959 to 1968 which was corrected for each year's fire danger rating shows that the FOR is rising over time (Ryan, 1971).

Second, the burned area rate (BAR) is:

$$BAR = \frac{AB * 1{,}000{,}000}{A * T} \qquad (8\text{-}2)$$

where AB is area burned. Table 8.1 shows that the burned area rate declined notably from 1966 to 1970. In Georgia, however, BAR has shown little trend over the last 10 years (Ryan, 1971).

A large number of factors, such as current temperature, humidity, and immediate past precipitation affect short-run fire danger, over a fire season. Local history of fire arson and fire protection effectiveness are known to be influential. But only a few factors likely to affect the FOR and BAR are associated with individual tracts. Unfortunately the magnitude of only several factors can be estimated. First, tract size is likely to be important since nearly all fires are man caused and small tracts have more perimeter relative to area than large. If exposure or risk (R) was proportional to perimeter (Pm):

$$R = k * Pm^{w}$$

where k is a constant and the perimeter is roughly proportional to square root of tract area (A):

$$Pm = m * A^{.5}$$

where m is also a constant. By differentiating, risk changes in proportion to the reciprocal of square root of area:

$$\frac{dR}{dA} = \frac{k * m}{2 * A^{\frac{1}{2}}} \qquad (8\text{-}3)$$

This relationship is perhaps too strong for fires that originate on the tract itself. But it is not too strong if the possibilities of fires starting on other tracts and spreading to the one under consideration. Adequate modeling of the effects of fire spreading from one tract to another is beyond this study.

Two other factors related to risk for a particular tract concern the amount of fuel present. If the stand has been thinned or has had severe storm damage in the last 5 years, the risk is approximately doubled (Craig, et al, 1945). It is estimated that controlled burning approximately halves the risk (Cooper, 1972). With these two factors and size, a fire occurrence index was devised:

$$FOI = \frac{7.07}{VA} * \frac{TH}{PB}$$

Where TH is 1.0 if unthinned and 1.8 if thinned and PB is 1.0 if unburned and 2.2 if burned, and 50 acres the estimated average tract size in the South. The probability of fire occurrence on a single tract (PF) is then:

$$PF = \frac{320 * FOI * A * T}{1{,}000{,}000}$$

where the average occurrence per acre per year must be weight by acres (A) and years (T).

Fire size. A distribution of fire sizes was computed from the annual fire statistics. They are shown in table 8.2, and the distribution is plotted in figure 8.2. A log-log regression of the form seemed to fit the data:

Figure 8.2--Probability of a wildfire being less than a given size in the South in period 1966 - 1970.

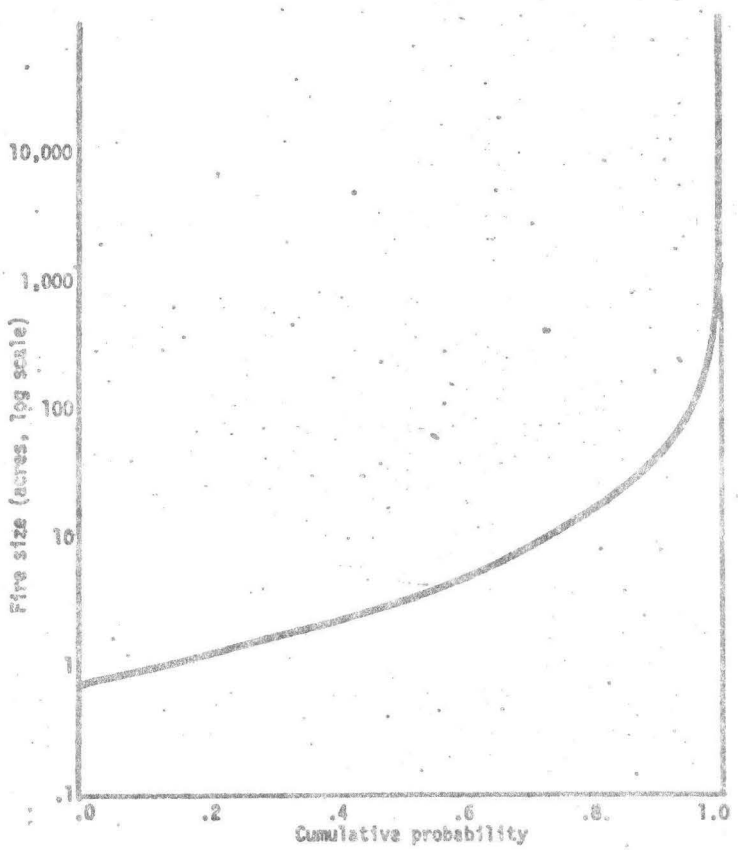


Table 8.2--Number of fires and acres burned in South, 1966-70.

Size	Year 1966	1967	1968	1969	1970	Total	Cumulat. Proport.
	Number of fires						
A	5,336	6,844	6,180	5,676	7,825	31,861	.0987
B	38,954	46,399	46,216	43,414	42,832	217,815	.7736
C	12,426	14,588	13,266	12,013	13,365	65,658	.9770
D	1,311	1,380	1,060	992	1,043	5,786	.9949
E	377	356	231	155	239	1,358	.9991
F	99	66	29	24	33	251	.9999
G	6	4	0	2	2	14	1.0000
	Acres burned						
							Average
A	1,031	5,688	1,415	1,300	612	10,046	.3
B	130,600	170,768	161,689	155,791	149,472	768,386	3.5
C	394,239	474,122	420,740	384,544	412,926	2086,571	31.8
D	225,145	237,216	182,458	169,105	170,479	984,403	170.1
E	192,170	181,333	129,982	80,437	109,149	693,071	510.4
F	170,828	101,515	47,080	47,265	64,069	430,751	1716.1
G	60,465	36,165	-	22,380	12,416	131,426	9387.6

$$\log_{10}(SIZ) = b * \log_{10}(1 - P) + c * [\log_{10}(1 - P)]^2$$

where SIZ is average size of fire by class and P is cummulative probability formed the relationship.

$$\log_{10}(SIZ) = - 1.44730 * \log_{10}(1 - P) - 131949 * [\log_{10}(1 - P)^2] \quad (8\text{-}5)$$

The equation was deliberately fitted to approximate estimates of large fires most closely. The R_2 for the analysis was .993.

Since the same effects that increase the fire occurrence rate affect the size of fires, the $\log_{10}(1 - P)$ is divided by the FOI which tends to increase the size of fires in hazardous situations and decrease them when hazards are low.

The area of fire on a tract, of course, cannot exceed that of the tract. In such cases it is assumed that the fire would spread beyond the tract. Inclusion of the tract perimeter compensates for fires spreading from other tracts. Small tracts thus have relatively high total losses than small ones.

Extent of damages. The intensity of fire kill in terms of basal area is also related to fire size, as well as other factors. The inverse cumulative probability distribution in figure 8.3 was developed from judgments of authorities on fire damage. This data was fitted to an equation of the form:

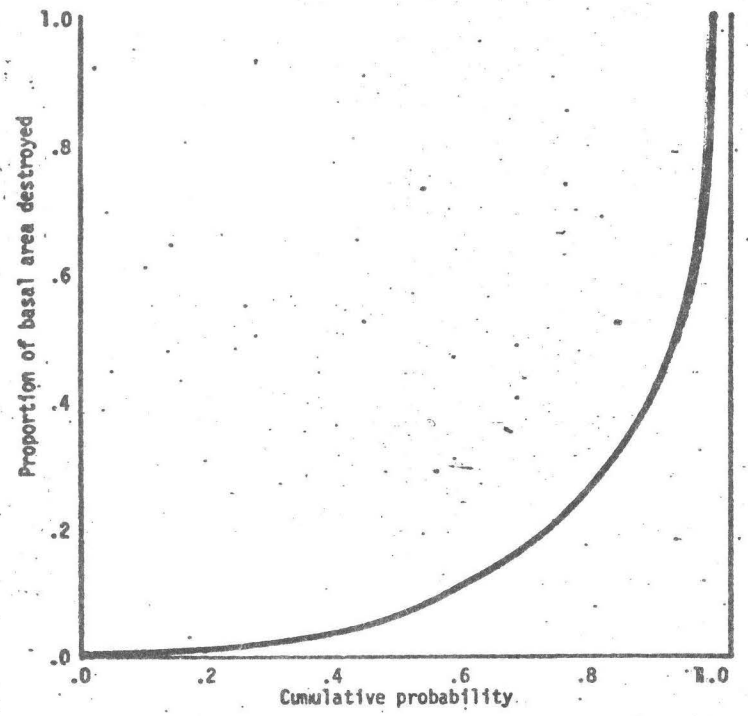
$$PBA = \frac{(BA\ loss)}{BA} = a + b * P + c * P^2 + d * \frac{1}{(1 - P)} \quad (8\text{-}6)$$

The resulting equation was:

$$PBA = - .14808 - .16960 * P^2 + .15292 / (1.1 - P)$$

with an R^2 of .993.

Figure 8.3--Probability that a fire would kill less than a given basal area of the stand. Based on estimated relationships.



Applying the relationships. In estimating whether a fire will occur, the size of fire, and the basal area damage, three random numbers are generated between .0 and .1, indicated by P_1, P_2, and P_3. PF is then computed from FOI, acres, and time period. A fire occurs if $P_1 > PF$.

If a fire occurs the adjusted cumulative probability of the size is:

$$P_{2a} = 10^{[\log_{10}(1 - P_2) * FOI]} \qquad (8\text{-}7)$$

which incorporates the severity of fire hazard into the random estimation of fire size. This is entered into formula 8.5.

The probability of basal area damage is closely related to the size of fire. The best means of incorporating this into the relationship is to compute the cumulative probability of damage as the geometric mean of the probability of fire and the third random probability:

$$P_{3a} = P_{2a} * P_3 \qquad (8\text{-}8)$$

The basal area damage is then determined by formula 8.6.

Storm losses

Tropical storms (hurricanes and other severe wind storms) and ice and glaze cause appreciable damage to southern pine stands. For both of these types of losses the data are quite inadequate but the impacts on stands are similar. They will be handled together.

Frequency of hurricanes and other tropical storms varies from relatively heavy along the Gulf and lower Atlantic coasts, decreasing in frequency and severity inland. On the other hand, glaze storms are not generally experienced in most of Florida and southern Georgia,

but increase in frequency and number with elevation and distance from the coast (Cool, et al, 1971). Though the records are spotty, either one or the other type of storm affects most general areas in the southern pine region on the average of once each 10 years, with an occurrence probability of .1.

Most storms significantly damage, however, only 20 percent of the stands within the area they affect due to local conditions, storm gusts, and a wide variety of factors. Since there is no effect on size of tract, the net probability of affecting a stand is roughly .02 per year.

Damage in terms of basal area varies from slight to nearly total loss. Using a rating system developed for glaze damage (Cool, et al, 1971), damage may range from 12 to 65 percent of basal area. Trees of all sizes relative to the average diameter are damaged. Since there is no other basis a distribution of damage extends linearly relative to cumulative probability from 10 to 70 percent. The equation for basal area loss is:

$$BRATE = .12 + .53 * P \qquad (8\text{-}9)$$

Damage to stands, however, is related to a number of stand attributes. Both types of storm (Cool, et al, 1971) damage relatively tall slender trees grown under dense basal areas. Perhaps the best variable to express this factor is the ratio of diameter to height of the average tree. A second factor was that damage to plantations younger than 10 years was mostly in the form of bending of the tops or partial uprooting. Nearly all of the trees recovered in the course of time.

Thus a storm damage index (SDI) was constructed in the functional form of:

$$SDI = .03 * \frac{H * T^{.5}}{D} \qquad (8\text{-}10)$$

where H is stand height, T is stand age, and D is diameter. If the stand was thinned in the last 5 years the H/D ratio employed measurements before thinning.

Applying the relationships. Two random numbers are generated between .0 and .1, labeled P_4 and P_5. Storm damage occurs if P_4 .02 * T. If the stand is damaged the cumulative damage probability is adjusted by the SDI by:

$$P_{5a} = 10^{\log_{10}(P_5)} * SDI \qquad (8\text{-}11)$$

The basal area loss is computed by applying P_{5a} to equation 8.9.

Insect losses

A number of insects affect southern pines. One type affects plantations made shortly after a pine stand is cut. Poles weevils infest the stumps of the cut trees and later will attack the base of seedlings if planted within a year of harvest. For this reason the planting of cutover areas in the model is delayed one year and yields are computed as if the plantations were one year younger than nominal age.

The second type is far more important economically. Five species of the bark beetles--the southern pine beetle (Dendroctonous frontalis), three species of engraver beetles, and the black terpentine beetle (D. terebrans) all cause substantial mortality under warious conditions. Total loss from these insects may be 50 million cubic feet per year valued at perhaps $10 million dollars (USDA Forest Service,1958).

The southern pine beetle causes the most spectacular damage by epidemic attacks which destroy large volumes of timber in localized areas at infrequent intervals of time (Thatcher, 1960). Southern Ips beetles and black terpentine beetles, on the other hand, are widely dispersed, seldom killing more than a few trees in one location except during adverse weather and after cutting. Over the years, however, they probably destroy more timber than does the southern pine beetle.

The species differ greatly in their life histories and their effects on host trees. Weakened or dying trees, rather than healthy green ones, may be considered their normal environment. In such material they are generally innocuous, though they may hasten deterioration. It is their ability to leave their normal hosts and destroy apparently healthy trees that make them important.

The beetles spend nearly all their lives in the cambium and inner bark of their hosts. Construction of egg galleries by the adults and subsequent mining of larva girdle the tree. This girdling, plus the introduction of fungi, kills the host tree. A tree may be killed by the attacks of a single beetle species, but commonly two or more are present. Zones of occupancy overlap, making it difficult to determine the primary attacker. All bark beetles will be considered together in the simulation model.

In a single year in the southern pine type there may be as many as 25,000 separate identifiable attacks of substantial magnitude. This may be related to the area in southern pine types to get a beetle attack rate for the area.

$$BAR = \frac{25{,}000 * 1{,}000{,}000}{98{,}600{,}000} = 254.$$

This beetle attack rate is influenced by a number of factors for individual stands (Thatcher, 1960, Bennett, 1968, Lorio, 1972). The past moisture condition of the soil and lightning strikes are among the primary causes. Among those that are influenced by management actions or stand conditions are:

1. Presence (+ 1.4) of the slash from thinnings, fire or storm or absence (1.)--variable SL.

2. Dense stands of pulpwood and pole sized timber:

$$PP = \frac{S}{[\ TD - 81 + 2] * 20}$$

3. Rate of mortality during current period:

$$MT = (1. - N_{t+1} / N_t) * 4.$$

The index for beetle attack is:

$$BAI = SL * PP * MT$$

The distribution of area affected by single attacks is not well documented. It is particularly subject to climatic cycles and regional programs to suppress epidemics and promptly salvage infected timber. A reasonable distribution for moderate conditions is similar to the distribution of sizes of fires, with many attacks of an acre or less and a few that reach major importance. In lieu of better information the same distribution as for fires is used (equation 8.5).

The impacts of the attack on basal area of stands is total. All trees are killed within the size of area as determined above.

Application of the relationship. Two random numbers between .0 and .1 are generated (P_6 and P_7). If:

$$P_6 = .000254 * A * BASI$$

on insect attack occurs. The size of the attack is also influenced by the beetle attack index, and the cumulative probability if affected as follows:

$$P_{7a} = 10. [\log_{10} (P_7) * BAI]$$

This probability is used in equation 8.5.

Disease losses

Two major fungal diseases affect southern pines with sufficient significance that they should be recognized in the simulation model. But both have significant impacts only on planted stands.

Fusiform rust. Cronartium fusiforme infects main and lateral shoots of young pines causing elongated cankers. If the canker is on the main stem or it reaches there from a branch, the tree is eventually girdled and killed before the tree reaches sawlog size. A variety of oaks, almost universally present, are alternate hosts of the fungus (Czabator, 1971).

Throughout most of the south at least some trees in almost all plantations are affected. Thus probability of attack will be assumed to be 1. In addition all of a plantation's area is exposed so that the size of the area affected is the entire stand. The only aspect left is the degree of infection.

The degree of infection varies by area in the south, by geographic race of loblolly pine used as the seed source, and other factors (Wells and Wakeley, 1966). The most susceptible varieties cannot be feasibly planted in many areas. Prospects for long term control of the disease lie in breeding resistant genes into the most adaptable planting stock for each locality.

Statistics on the incidence of the disease are scarce. The best source available is that of the Southwide Pine Seed Source Study which has tested 15 sources of seed in 10 planting sites. With some omissions, 110 test plantings were examine for fusiform rust infection. The inverse cumulative distribution of rates of infection are shown in figure 8.4. The most practical probability function for percent trees fatally infected at age 10 is:

$$PK = a * P + b * P^2 + c / (1.1 - P)$$

This was fitted to the data by regression, resulting in the following equation:

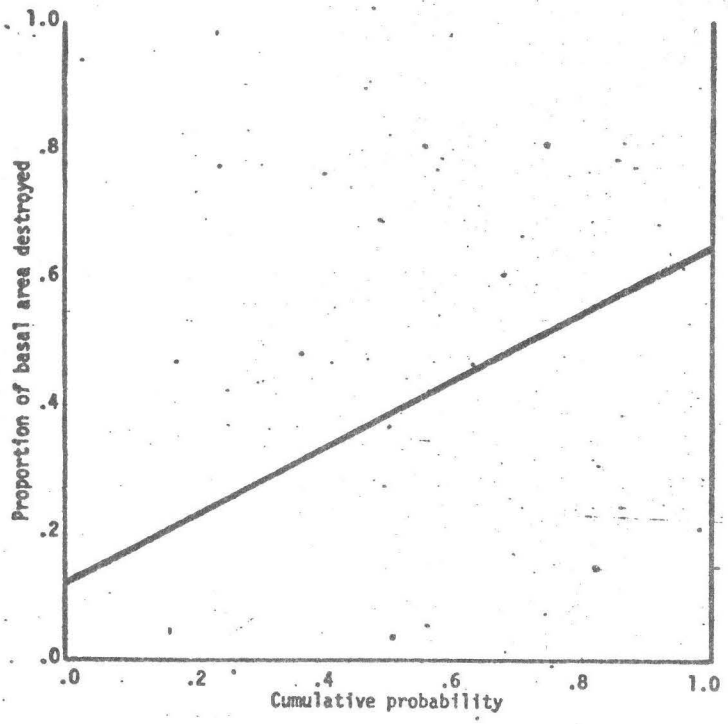
$$PK = .20599 * P + .95018 * P^2 - .23223 / (1.1 - p)$$

There are two problems associated with this estimate of infection. First, some infections may be on branches that die before the fungus reaches the main stem or may be removed with little loss as thinnings. Second, the Lenhart-Clutter yield study includes yields from plantations with small but unknown rust infections. Thus the net effect may not be as great as the proportions infected suggest. No definite data exist by which to estimate these impacts. The best estimate of the distribution of infection at age 10 is shown by the dotted line.

The disease has given rise to an important modification of planting technique in areas of prevalent fusiform infection. Excess trees are planted and the stand is thinned at age 5 or so with a brush hook to reduce stocking to the level desired. This procedure will be analyzed separately in Chapter 11.

Fomes annosus root rot is a potential cause of loss in plantations. The fungus is a major natural cause of decay in stumps and down slash in

Figure 8.4--Probability of having less than a specified rate of fusiform rust infection in planted loblolly pine stands.



pine forests but may spread from roots of dead trees to the root systems of live trees. Infected trees are easily windblown and the typical white stringy fungus exposed. However, standing trees with extensive root rot decay may remain green for a time, making detection difficult (Powers, and Verrall, 1962, Morris, 1970).

Intensive plantation management of southern pines, with close, uniform spacing, root malformation and damage in planting, and early and infrequent thinnings, favors infection and spread of the disease. It is seldom a problem in natural stands, for unknown reasons. It is also less frequent in unthinned plantations.

In a survey of nearly five hundred thinned plantations, losses were recorded in about 59 percent of planted loblolly pine plots and only 8 percent of natural plots (Powers and Verrall, 1962). There are several significant variables affecting this other than the stands had to have been planted and once thinned. In addition there is evidence that damage is higher on old fields than on cutover stands and greater damage on better sites than poorer.

Though the disease is of present major concern, recent breakthroughs in control procedures using borax compounds and non-spreading counter-fungi offer excellent promise by the time any future plantation matures (Ross, 1971).

Summary

This chapter develops a unique approach to estimating impacts of losses from natural causes on financial returns from timber growing. The impact is separated into probability of a loss occuring on a tract,

the area involved, and the proportion of basal area killed or injured.

This approach is applied to five of the major types of losses in southern pine management: fire, tropical and glaze storms, bark beetles, fusiform rust and annosus root rot. The probability distributions that are incorporated into the simulation system are described.

Chapter 9

IMPACTS OF FEDERAL INCOME TAXES ON TIMBER GROWING

An important modifier of financial returns from timber growing is the impact of federal income taxes. The income tax in particular is not neutral. It has a differential effect on:

1. Timber growing versus other land use.
2. Different timber management strategies.
3. Different owner classes.

This chapter, however, will discuss in simplified form the federal income taxes as they apply to timber growing.[1/] Throughout the discussion it will be assumed that land owners take advantage of the provisions applicable to their tax situation.

As presented in Chapter 3, the evaluation of timber growing investments is based on the effect the investments have on the owner's monetary stream of net income and capital value over time. All considerations arising from the timber investment, even indirect, that affect the stream of income should be included. Federal income taxes affect both the positive impacts (revenues from sales) and the negative impacts (cost and losses).

Income from timber production is accorded special treatment under the Internal Revenue Code.[2/] These provisions have a rich

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1/ Property taxes in this study have been treated as an ordinary cost and will not be treated separately, since they do not in themselves discriminate between owner type or management level, even though administration may be uneven.

history and have been subject to several economic analyses (Mead, 1966; U.S. House of Representatives, 1963; U.S. Treasury, 1968; Sunley, 1972). This study will simplify these provisions and incorporate them into the simulation system to measure the impact on net income of different types of owners. It will ignore costs of roads and other developments and leasing and other arrangements. The special tax features applying to otherwise tax exempt income provided in the 1969 Tax Revision Act will also be omitted.

Tax impacts on revenues

Timber growing differs from most productive processes in that the output from an operating unit is often not sold annually, but is accumulated for a period of years and forms part of the productive capital of the ownership. Thus what would ordinarily be called "income" is automatically transformed into capital goods.

In most other sectors of the economy capital goods are created by identifiable acts of investment. This investment expends previously accumulated funds arising from savings of income (on which income taxes have already been presumably paid) or from sale or exchange of other forms of existing capital. Thus income arising from productive processes or labor is normally quite distinct from changes in value of existing forms of capital. The federal tax laws are able to assess taxes on them in quite separate ways--with taxes on ordinary income substantially higher than on capital gains. Revenue from timber growing is one of the few forms of productive income that are generally allowed to be taxed as capital gains.[3/]

Virtually all proceeds from the sale or other disposal of timber (after deduction of depletion) are eligible for long term capital gains treatment provided (a) the timber was not held for sale "in the ordinary course of business" and (b) the timber was held for more than six months. Because uncertainty may exist in some situations as to whether the timber was in fact held for sale in the ordinary course of business, forest owners making repeated sales of timber often sell on a scale basis in order to retain an "economic interest" in the timber and thus qualify for capital gains treatment under a special provision of the Code (Section 631b).

The effect of any tax on revenues is to effectively reduce the net cash income from them. There are two aspects of determining the magnitude of the tax impact--or "bite".

Calculating net revenue

Not all of the proceeds from the sale of output are economic gains. The costs of producing them must be deducted. In timber all of the costs of producing timber that have not already been accounted for in income taxes are either "costs of sale" or "depletion".

The costs of sale include tree marking, appraisal, advertising, legal fees, and similar costs incurred at the time of sale or harvest.

2/ The best description of the federal income tax provisions affecting timber are in: The timber owner and his federal income tax (USDA Forest Service, 1971), and Briggs and Condrell (1969).

3/ There is relatively little argument that the changes in value of existing timber from the time the timber was acquired by the owner until the time he disposes of it are capital gains and should be taxed as such.

Depletion is the share of accumulated costs (including original timber acquisition cost) that have been expended previously to produce the timber. These costs are accumulated in the capital accounts required by the Internal Revenue Code.

The capital accounts

Many types of investment cost in timber growing are regarded by the Internal Revenue Code as capital expenditures that may not be deducted by the owner as paid or incurred. They must be "capitalized" --setup in the owner's tax records through charges to one or more capital accounts. These accounts are:

1. The land account, including acquisition cost plus all fees for services required in acquisition, such as cruising, appraisal, survey, title search, and recording and legal fees. In the simulator, all of these items are collectively handled as one land value, since they have essentially no effect on the tax situation until the land is sold. The present study assumes no land is sold.

2. The timber account, with the following items charged to sub-accounts: (a) acquisition cost of merchantable timber, (b) acquisition cost of unmerchantable young growth, and (c) regeneration or reforestation account. As unmerchantable timber on acquired or regenerated tracts become merchantable, the value is transferred to the merchantable timber subaccount. Since the trials in this study start with regeneration, only the regeneration subaccount, and late the merchantable timber account are active. The purpose of the timber account is to permit calculating the depletion allowed on timber

cut (cost or other basis for gain or loss on timber sold or otherwise disposed of, or lost by wild fire or other casualty).

3. The equipment account, charged with acquisition cost of all durable equipment connected with the forestry operation. In this study the account is not used.

The original account values at time of acquistion or reforestation must be adjusted year by year by the following occurrences:

1. Purchase of additional timber on other tracts in the same management unit or block. (Also not considered in this study.)

2. Capitalization of expenses.

3. Sales of timber.

4. Casualty losses, such as fire or storm.

5. Transfer of timber from young growth or plantation subaccounts.

In addition to dollar values, the timber account must also record original volume in merchantable units. This volume must be adjusted in a manner similar to account values for all changes, including periodic addition of accumulated growth. If the volume and value of the timber when acquired are unknown, a professional estimate of the amounts may be necessary.

The gain or loss for tax purposes is computed as the difference between the amount received and the prorated cost or other basis of the timber. The cost or other basis is the amount in the timber capital subaccount for the owners merchantable volume. Thus the gain on timber sale is:

$$GAIN = R - CT * Y_u / Y_c - MC$$

where $\underline{R}$ is revenue, $\underline{CT}$ is the timber account value, and $\underline{Y_u}$ and $\underline{Y_c}$

are uncut and cut volumes, and MC the marking and sales cost. The volume in the timber subaccount is of course subsequently adjusted by the volume cut. The cash gain is the total revenue less the sum of the income tax and the marking and sales cost.

$$NR = R \quad RAG * GAIN - MC$$

where RAG is tax rate on capital gains.

Tax rates and application

The effective tax rate, on both ordinary income and capital gains, depends on the tax situation of the owner. Different provisions apply to corporations than to individuals. The tax rates that apply are summarized as follows, with TR indicating an individual taxpayer's marginal tax rate, after first netting out long-term and short-term gains and losses.

	Capital gains[4/]	Ordinary income
Individuals; if at the margin the owner has:		
Less than $50,000 long-term capital gains	The lessor of TR/2 or 25%	TR
More than $30,000 long-term capital gains	TR/2	TR
Corporations; if at the margin the owner has:		
Less than $25,000 taxable income	22%	22%
More than $25,000 taxable income	30%	48%

4/ The additional tax applying under certain circumstances to otherwise tax exempt income is not included.

To illustrate the computation of capital gains and the tax that applies to it, assume that a forest owner makes a thinning of 50 percent of the volume of a tract that has 100,000 cubic feet of wood on it, that the cost or other basis in the timber subaccount for the tract is $5,000, and that his tax rate on ordinary income is 40 percent and on capital gains is 20 percent. The net proceeds of the sale taxed as capital gains and as ordinary income is:

	Taxed as:	
	Capital gains	Ordinary income
Receipts from sale	$10,000	$10,000
Marking and sales cost	500	500
Net revenue	$9,500	$9,500
Cost or other basis for tract	(5,000)	(5,000)
Prorated share	2,500	2,500
Gain or income	$7,000	$7,000
Tax	1,400	2,800
After tax revenue	$8,100	$6,700

Tax impacts of costs and losses

In addition to their impact on net revenue, items that reduce income or capital value have various tax treatments that have implications on financial evaluation.

Treatment of various classes of expenses

Timber owners must carefully distinguish between costs of production that are permitted to be charged off as current expenses, and those that must be capitalized in the capital accounts. As will be shown,

Precommercial thinning

Cull tree removal

Hardwood spraying

Fire protection (including controlled burning)

Disease and insect control

Carrying charges such as:

Property taxes

Interest on loans

To illustrate the impact, consider two costs, A and B. A can be expensed or offset against other income taxed at 40 percent, and B must be capitalized and recovered only at the end of 30 years by depletion. At that time, it is subtracted from capital gains taxed at 20 percent. The net present value of these two expenses are:

	Cost A	Cost B
Immediate cash outlay	$1,000	$1,000
Reduction from present taxes	400	
Reduction from taxes in 30 years		(200)
Present value of this reduction		75
Net after-tax outlay	$600	$925

Treatment of losses from fire, storm, insects and disease

Whether losses from various agents can be deducted from other income depends on the extent the loss meets legal definitions of a casualty of the Internal Revenue Code and court decisions. In general the major criteria are the suddenness and unexpectedness of the loss. The legal problems in afirming casualty losses in forestry are

discussed by Siegel (1971).

For this study, fire or storm losses will be considered casualty losses. This will reduce the owner's tax on other income to the extent of the owner's marginal tax rate, in effect crediting the timber growing enterprise with a financial return. Losses from bark beetles, cronartium rust, and Fomes annosus root rot will not be considered casualties.

To illustrate the impacts of this provisions, assume that two losses occur in a stand at age 20 that would cause $1,000 losses in merchantable value of the stand at that time. Both would reduce the value of the harvest at age 30 by $1,600. The present value of the loss can be calculated as follows:.

At stand age 30	Casualty loss	Non-casualty loss
Reduced sales revenue	$1,600	$1,600
Less reduced tax (20 percent)	320	320
Net value at age 30	$1,280	$1,280
At stand age 20		
Value of income at age 30, discounted from above	786	786
Offset against other income	(1,000)	
Reduced tax on ohher income	400	
Net value at age 20	$386	$786
At stand age 0 (present)		
Value of income at age 20, discounted from above	$145	$296

Thus in this illustration, the provision reduces the risk of future loss by half in terms of present value at the beginning of a rotation.

The income tax simulator

The financial returns simulator incorporates a subroutine that modifies the schedule of costs and returns from timber growing to approximate the impact of federal income taxes for different classes of owners.

For each owner class four items of information are required for this income tax simulation:

1. Individual or corporation status.
2. Tax rate on additional ordinary income (in decimals).
3. Tax rate on capital gains (in decimals).
4. Whether operating expenses can be deducted from other income. (0 - No; 1 - Yes)

The initial status of timber and land capital accounts is established from information generated by the trial simulation. The routine makes several assumptions: (a) the ownership of the timber will not change during the trial period, (b) the owner's income is stable and the situation specified is his long-term average tax situation, (c) that federal income tax provisions will not change substantially, (d) that the land is developed in the sense that roads and permanent structures like fire towers and operation buildings have been built, and that maintenance and replacement of such permanent improvement are covered by management expenses, and (e) the owner contracts to

vendor firms operations that would require additional capital investment in equipment if performed by the owner.

At present the simulator can prepare modified schedules of returns and costs for four different tax situations for each physical yield trial. In addition to the difference in tax status, the owners may also differ in other attributes--principal acreage owned and guiding rate of return.

The TAX subroutine is called to enter the processing at four different points.

1. At trial initiation to establish initial values in the capital accounts --either land or timber acquisition cost.

2. As each cost is incurred to determine the net out-of-pocket-cash requirements and whether the costs must be added to each owner's capital accounts.

3. As timber is cut (or other income is received) to determine net after-tax revenue, and if appropriate, to adjust the capital account.

4. If major losses occur that are tax deductible, to determine the effect on the owner's income tax.

Summary

The principal advantages from the provisions of the federal income tax laws affecting timber are (1) capital gains treatment of income realized upon disposal derived from an increase in value of standing timber, either from an increase in unit value or growth, (2) the privilege of expensing some production expenses against

current ordinary income, and (3) expensing losses in yields, reducing their impact sharply. The result is substantial reduction of tax rates compared to other productive processes.

The simulation of the effects of this tax treatment will be discussed in Chapter 11.

In Chapter 10, dotted lines in titles, are shown as light lines, and solid lines as heavy lines.

Chapter 10

SIMULATIONS OF ALTERNATIVE MANAGEMENT REGIMES

Chapters 3 and 4 of this study present the basic rationale and outline of the simulation model and computer program. Chapter 5 discusses the biological models of stand establishment and subsequent growth of both naturally regenerated and planted stands. Chapters 6 and 7 describe the price and cost relationships developed for this study, and Chapter 8 and 9 discuss important modifiers to the economic production process--risk of loss from fire, disease, insects, and storm, and federal income tax provisions. This Chapter seeks to integrate this information using pre-tax financial returns from the deterministic model to select a group of alternative management schedules for major production opportunities. The following chapter will determine which of the selected alternatives appear most promising for each of 4 types of owners using after tax returns from probabilistic procedures developed in Chapter 3.

The simulation model, fleshed out with the biological, price, and cost functions, provides what might be considered a highly flexible experimental tool to test the sensitivity of the model to natural conditions and decision parameters. Most important are the site productivity (SI), tract acreage (A), rotation length (tz), reserved basal area (BG) and establishment cost (EC). In this Chapter sensitivity tests of these variables

are used to indicate which management regimes are most promising. These tests will indicate how the results compare with previous economic analyses of growing southern pine that have used simpler models.

The presentation establishes a number of hypothetical timber growing situations or opportunities based on information of Chapter 2. For each basic opportunity, several alternative regimes and refinements for each of the seven general levels of management described in Chapter 2 are simulated and analyzed. The management levels will be examined in order of increasing capital and management intensity. For each opportunity and management level three of the many possible alternative regimes will be selected for study in Chapter 11.

In order to include the alternatives most likely to be optimum for any owner, the criteria used for selecting alternatives for Chapter 11 are: (a) the highest equivalent annual income at a guiding rate of 5 percent--the "income option", (b) the highest rate-of-return--the "return option", and (c) a "compromise option". This Chapter will assume pre-tax returns from relatively large tract sizes--200 acres--and no expected increases in prices and costs.

Modal opportunities

To formulate and test alternative regimes, they need to be applied to a number of representative timber growing situations.

To reduce the complexity of presentation, only a few types of land are considered. The land is assumed to be at the start of a timber production cycle.[1/]

The simplest opportunities are those on relatively bare land--either abandoned farm land or recently cutover forest land. Both of these types of land are either (a) surrounded by pine stands or (b) have sufficient viable seed on the ground to assure adequate regeneration. A somewhat more complex situation is degraded unmerchantable oak-hickory forest type. It is assumed to offer little prospect for financial returns without clearing and regenerating the timber stand.

The 9 opportunities are:

Abandoned fields, sites 60, 80, and 100

Cutover forest, site 60, 80, and 100

Upland hardwood on pine sites 60, 80, and 100

Old field and converted sites differ in important respects from cutover sites, as noted in Chapter 5. First, old field sites generally would be expected to regenerate sooner and with heavier stocking to pine than would cutover land with even a sparce understory of hardwoods. A converted hardwood site would be expected to regenerate largely to hardwoods unless planted. Thus the expensive treatment of clearing hardwoods was considered

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1/Many analyses of timber economics emphasize treatments to improve existing unmanaged stands (Anderson, 1966). But the decision on whether to treat a stand or regenerate it depends on prior realistic analyses of expected returns from regenerated stands. Thus analyses of timber stand improvement should be deferred for subsequent study.

only if the stand was to be planted.

Secondly, both old field and converted sites will automatically be cutover sites after the first rotation. Simulations that would assume perpetual rotations of old field or converted regimes would be illogical. For these lands the best management parameters for rotation age, basal area stocking, and other factors may vary from that for cutover land. In the simulations in this chapter, the annual income and rate of return from old field and converted lands assume a specified regime for the first rotation followed by a perpetual series of the best cutover management regimes for that site.

The approach to selection of efficient regimes starts with testing the principal management factors, rotation age, basal area stocking, and establishment treatment, within the range of the management guides now generally recommended by practicing foresters (Chapter 2). Sensitivity testing using a range of values for each factor can determine whether this conventional wisdom, whether based on financial analysis or not, appears sound.

Analyses of natural stand management

Management level I: Let it alone

The simplest management is expecting the timber to seed in naturally into the open fields and cutover areas or letting the hardwood stands alone. The owner allows the growth to accumulate and harvests at one time after the volume is merchantable. The only cash expenditures are property taxes and costs of cruising

the timber prior to sale.[2/]

As discussed in Chapter 5, the regeneration expected on cutover land without preparation is only partially pine. Hardwoods from sprouts or existing seedlings are likely to pre-empt high proportions of the area and limit the number of pine seedlings established and the rate of pine growth. Consequently the harvest diameter attained is only moderate. Recently abandoned crop land provides excellent growing conditions for seed from surrounding pine stand and seedling establishment is often high. The pine is likely to become established before hardwoods, so hardwood problems are minimal until first harvest.

The model was set up to simulate yields that would result from this minimal level of management.

The only relevant management decision parameter is the length of time to hold the timber until harvest. Longer rotations produce larger, denser, and thus more highly valued yields, tending to offset the increased length of time to obtain them.

Average expected returns. The model's estimates of financial returns before taxes depend on a number of factors. Figure 10.1 shows the equivalent annual income at various guiding rates of interest from site 80 cutover land and rotation lengths from

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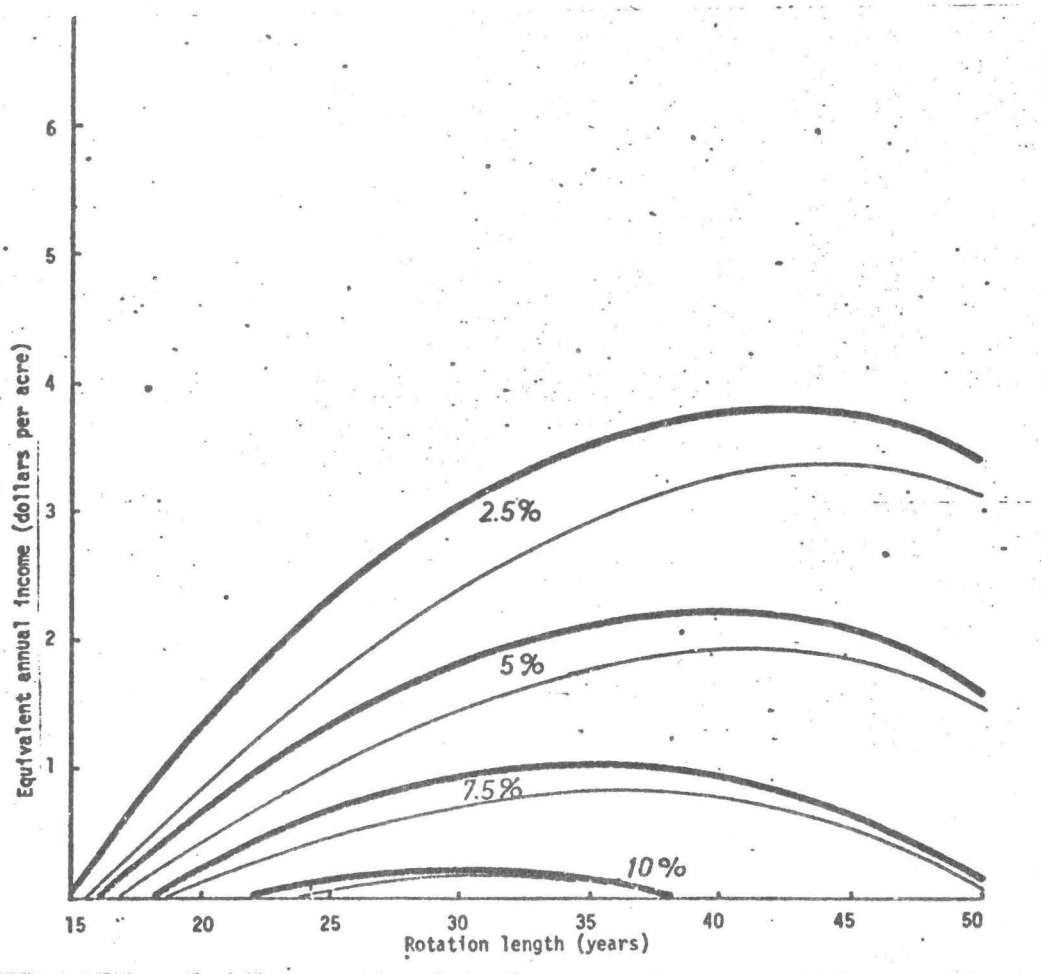
2/Though in fact often neglected under such management, the cost of a cruise can be justified by a prudent owner just to obtain an accurate estimate of the volume and value of sale.

Figure 10.1--Annual incomes per acre from management level I--unmanaged natural stands--on site 80 cutover land by rotation length and guiding rate-of-return. (Single rotation income is shown by dotted lines, perpetual series income by solid lines.)



15 to 50 years. The dotted lines show the equivalent annual income from the first rotation and the solid lines that from the first rotation plus the discounted returns from all future rotations. The difference between the two lines decreases with rotation age, indicating that the value of subsequent rotations tends to decline with rotation age.3/

As the interest rate increases, the equivalent annual income declines and the best rotation length shortens. For each rotation length the rate-of-return is the rate of interest at which the annual income is zero. The rate-of-return is thus the highest owner's guiding rate for which the returns for a specific alternative adequately compensates the owner. The rate-of-return criterion thus forms an outside "envelope" of possible least-intensive capital investment for owners with differing guiding rates and thus the shortest rotation that any owner would choose.

The appropriate rotation age for owners with 5 percent guiding rates is about 40 years. For interest rates of 8 to 10 percent the rotation length is about 30 years. For owners with such high guiding rates of interest that investments in management must yield maximum returns, the indicated "rotation age" or average length of holding timber is about 25 years. This agrees with the prevalent pattern of resource use on unmanaged lands.

3/Because rate-of-return calculations reduce the net value of a series or revenues and costs to zero, the rate-of-return for a single regime is the same as for perpetual series of similar regimes.

Figure 10.2 shows annual incomes (at 5 percent) and figure 10.3 rates-of-return by rotation length for each of the three site index classes of cutover land. The three sets of curves differ somewhat in shape. On site 60 land the timber never reaches large diameter sawtimber size and best rotations are heavily influenced by peak annual cubic foot growth rates. The curve for site 80 keeps climbing rapidly between ages 30 and 40 because the timber is entering the sawtimber size classes. On site 100 land the timber reaches sawtimber size earlier but returns keep improving until 40 because of increases in quality.

Similar results for old fields (figure 10.4) show much higher annual incomes than for cutover stands because of better regeneration stocking, even though the diameter at harvest age is not as great. Since old field stands after harvest would have the same characteristics as cutover stands the allowance for future rotations is based on the best perpetual cutover stand rotations.

Summary data for alternatives selected for further simulation are shown in table 10.1. The detailed records of the regimes are shown in Appendix II.

Management Level II: Hardwood control by site preparation and controlled burning.

Much of the variation in yields and loss of returns from leaving cutover stands to regenerate without treatment is caused by lack of disturbed soil seedbed and by regeneration of hardwoods along with the pine. Site preparation, which usually consists

Figure 10.2--Annual incomes per acre from management level I--unmanaged natural stands--on cutover land--by rotation length and site index. (Single rotation income is shown by dotted lines, perpetual series income by solid lines.)

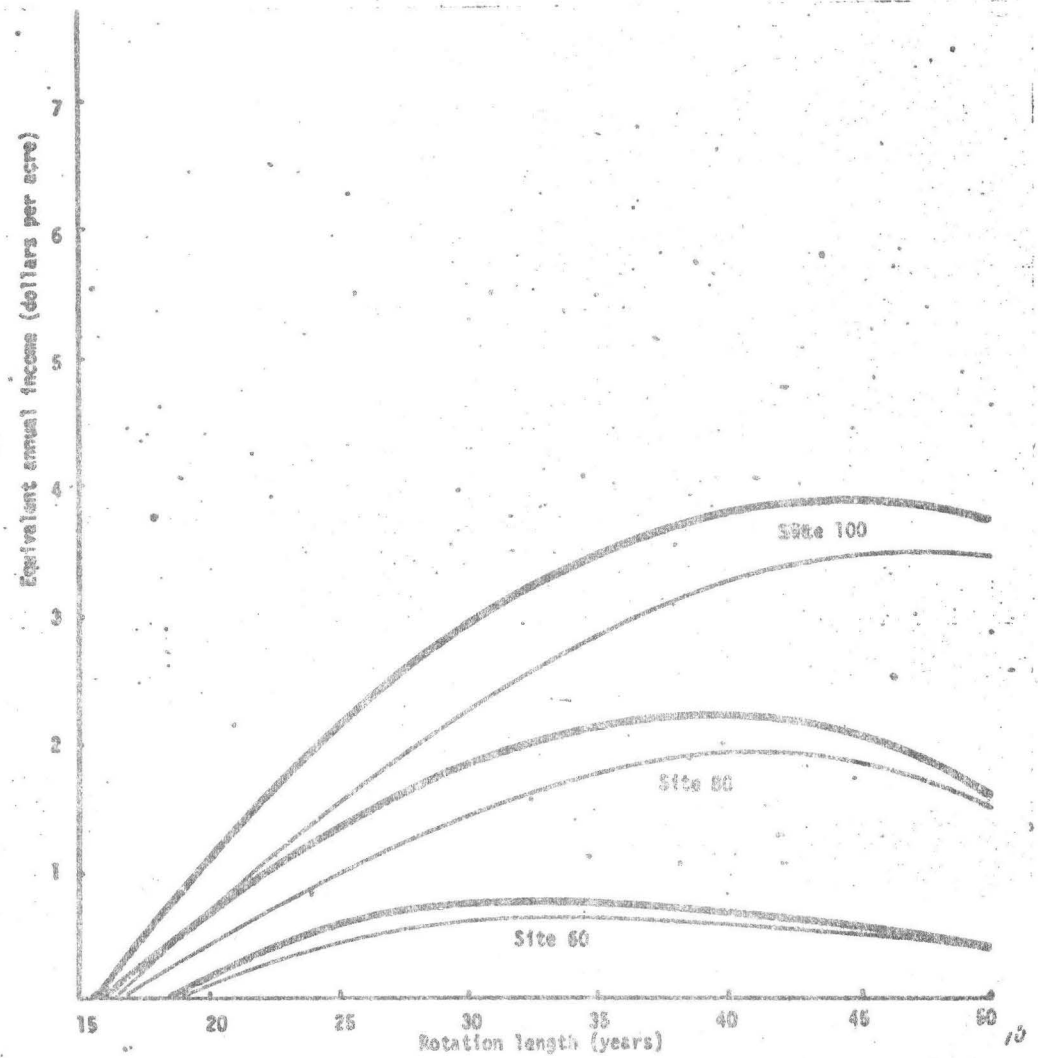


Figure 10.3--Rates-of-return from management level I--unmanaged natural stands--on cutover land--by rotation length and site index.

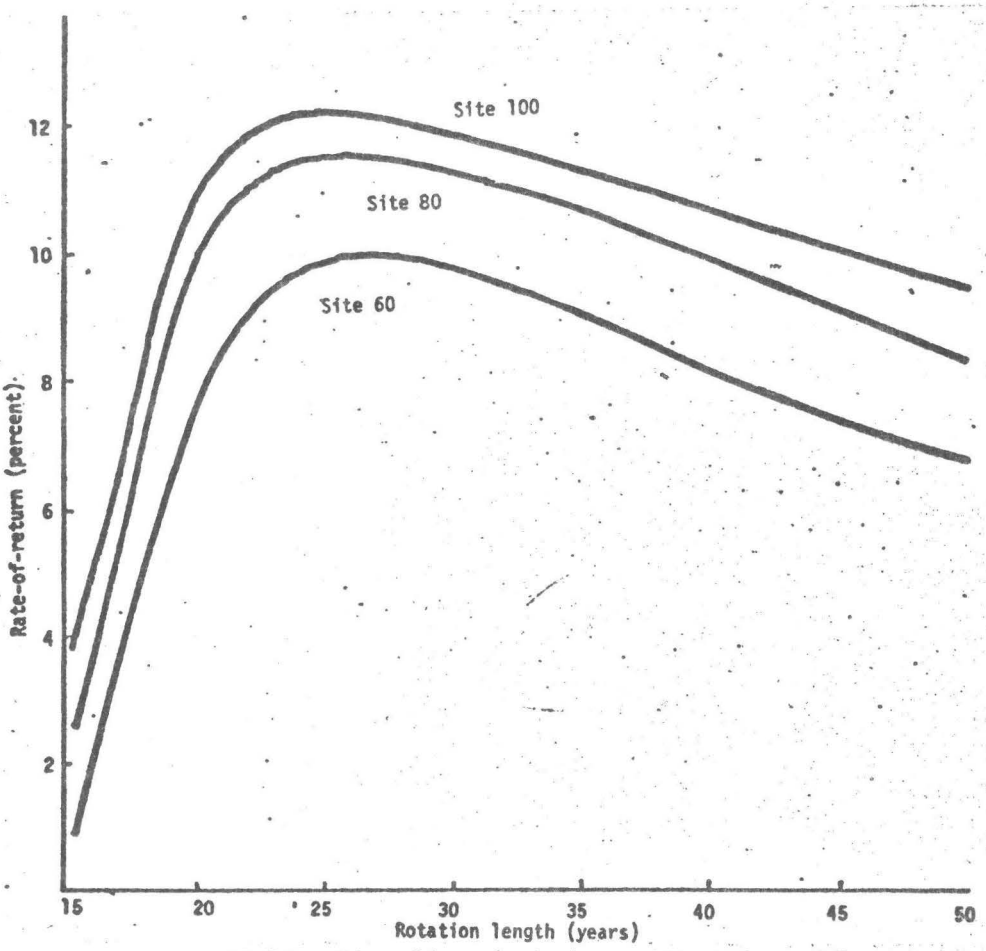


Figure 10.4--Comparison of annual incomes per acre from management level I--unmanaged natural stands--on old field land (solid lines) and cutover land (dotted lines) by rotation length and site index.

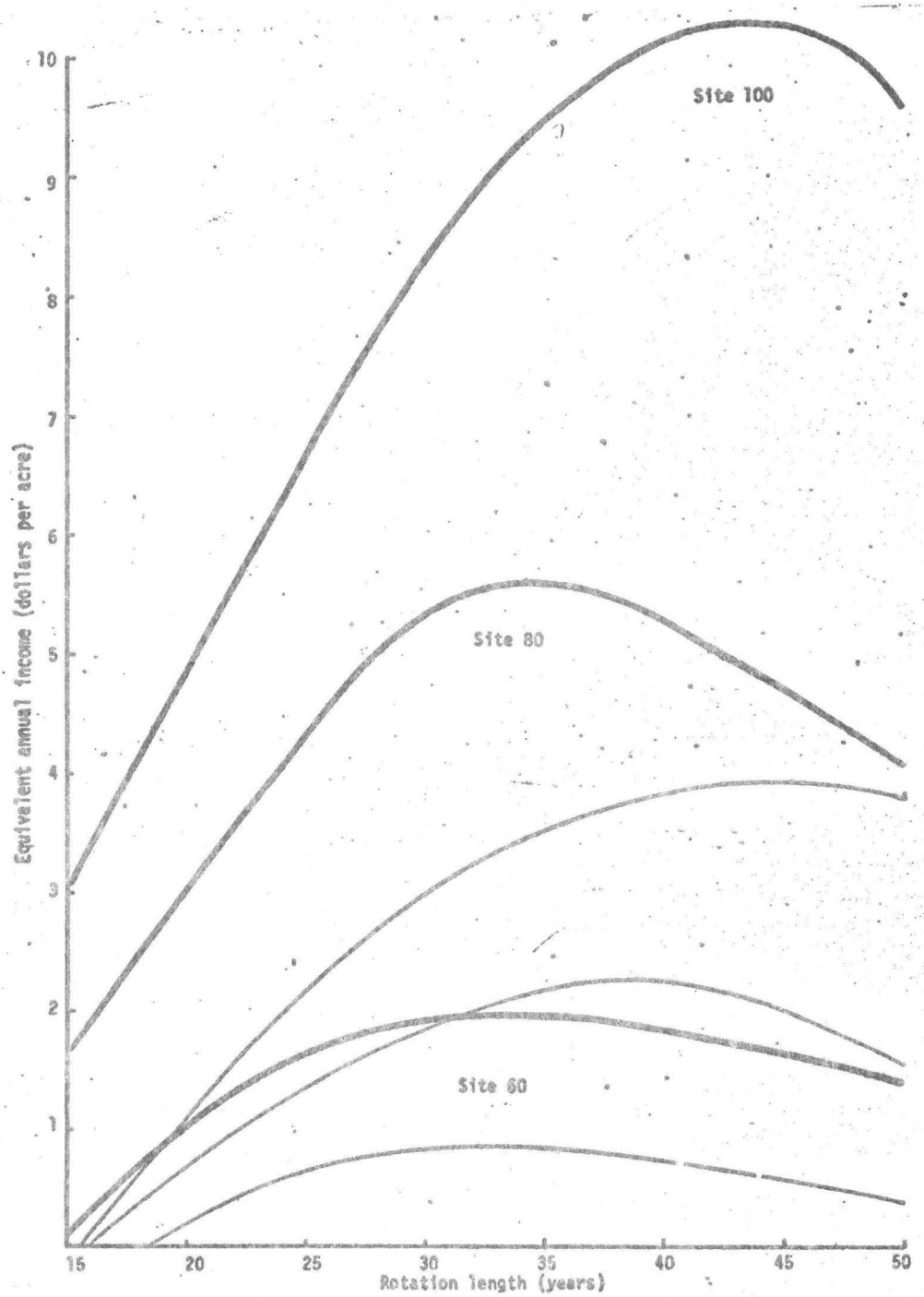


Table 10.1--Data for alternatives in management level I selected for further simulation.

Criterion and item		Cutover Site 60	Cutover Site 80	Cutover Site 100	Old field Site 60	Old field Site 80	Old field Site 100
Annual income criterion							
Annual income	($s)	0.81	2.18	3.91	1.97	5.42	10.66
Rate of return	(%)	9.0	10.7	10.0	12.1	16.1	12.8
Harvest age	(yrs)	35.	35.	45.	35.	30.	45.
Harvest diameter	(in)	11.1	30.1	20.5	9.9	11.9	17.9
Avg pine yield	(cuft)	24.8	40.6	58.1	49.8	83.2	115.8
Avg pine grow stock	(cuft)	371.	626.	1306.	676.	908.	2471.
Compromise criterion							
Annual income	($s)	0.80	1.86	3.51	1.95	4.34	8.36
Rate of return	(%)	9.8	11.3	11.3	13.5	17.6	16.7
Harvest age	(yrs)	30.	30.	35.	30.	25.	30.
Harvest diameter	(in)	10.1	13.3	18.3	9.1	10.6	14.8
Avg pine yield	(cuft)	24.3	40.2	61.2	49.7	80.8	126.8
Avg pine grow stock	(cuft)	286.	490.	955.	519.	639.	1420.
Rate-of-return criterion							
Annual income	($s)	0.65	1.39	2.18	1.67	3.00	4.81
Rate of return	(%)	10.2	11.5	12.2	14.9	18.5	19.5
Harvest age	(yrs)	25.	25.	25.	25.	20.	20.
Harvest diameter	(in)	8.9	11.7	14.6	8.1	8.8	10.9
Avg pine yield	(cuft)	22.5	37.8	57.4	47.5	71.7	110.6
Avg pine grow stock	(cuft)	194.	341.	528.	355.	367.	605.

of chopping or disking the soil by heavy equipment, reduces hardwood brush and exposes bare soil, thus improving chances for successful pine regeneration. The number of pine seedlings expected approximately doubles. Recently abandoned fields do not need site preparation. As mentioned in Chapter 7, there are several treatment intensities. The treatment has a fixed cost of $540 and a variable cost of $5 a acre for each degree of intensity. The average intensity depends on amount of slash and hardwoods and would average around the following levels:

	Site 60	Site 80	Site 100
Management level II	1.0	2.0	3.0
Management level III	1.5	3.0	4.5

A second practice assumed under this minimal level of management is controlled burning after the stand is established. Brush and accumulated litter on the forest floor can be burned at 5 year intervals in dry cool weather with little danger or harm to the pine.4/ The effect is to reduce hardwoods to almost insignificant levels by harvest time. Equally important, controlled burning sharply reduces fire hazard in mature stands. Its cost per acre for a 200-acre tract is about $1.50.

In addition to property taxes, nominal annual management

4/The usual interval of controlled burning is 2 to 3 years and depends on amount of litter accumulated. High sites tend to need burning more frequently than low sites. The practice has been critized on environmental grounds, because of the visible, if not harmful, smoke.

costs of 25¢ an acre are likely.

Expected average returns. The model, set up to these specifications, simulated the results using median expectations for establishment. It is at this level that results from yield studies, such as Schumacher and Coile (1960), are applicable with reasonable confidence.

Even low levels of site preparation treatment result in about twice as many trees and 75 percent more basal area. The trees, because of greater competition, are smaller. Site preparation and prescribed burning effectively reduce impacts of hardwood competition.

Equivalent annual incomes (at 5 percent) and rates-of-return for each rotation length appear in figures 10.5 and 10.6 for site indexes of 60, 80, and 100. The best rotation age for site 60 is now 35 instead of 30, and for site 100 the best age increases to 45. This general lengthening of rotation age is a response to the increase in costs--from an average of $.83 to $1.80 an acre over the rotation for site 80. It takes a longer period to recover these costs.

The most important effect is to sharply increase the differences between returns for each site index class. The treatments return only about 5 percent for site 60 but much higher rates for the higher productivity land. At 5 percent interest, the annual income for site 60 land thus remains the same, it increases 73 percent for site 80 land, and increases 91 percent for site 100 land.

Figure 10.5--Annual incomes per acre from management level II--low site preparation--on cutover land--by rotation length and site index. (Single rotation income is shown by dotted lines, perpetual series income by solid lines.)

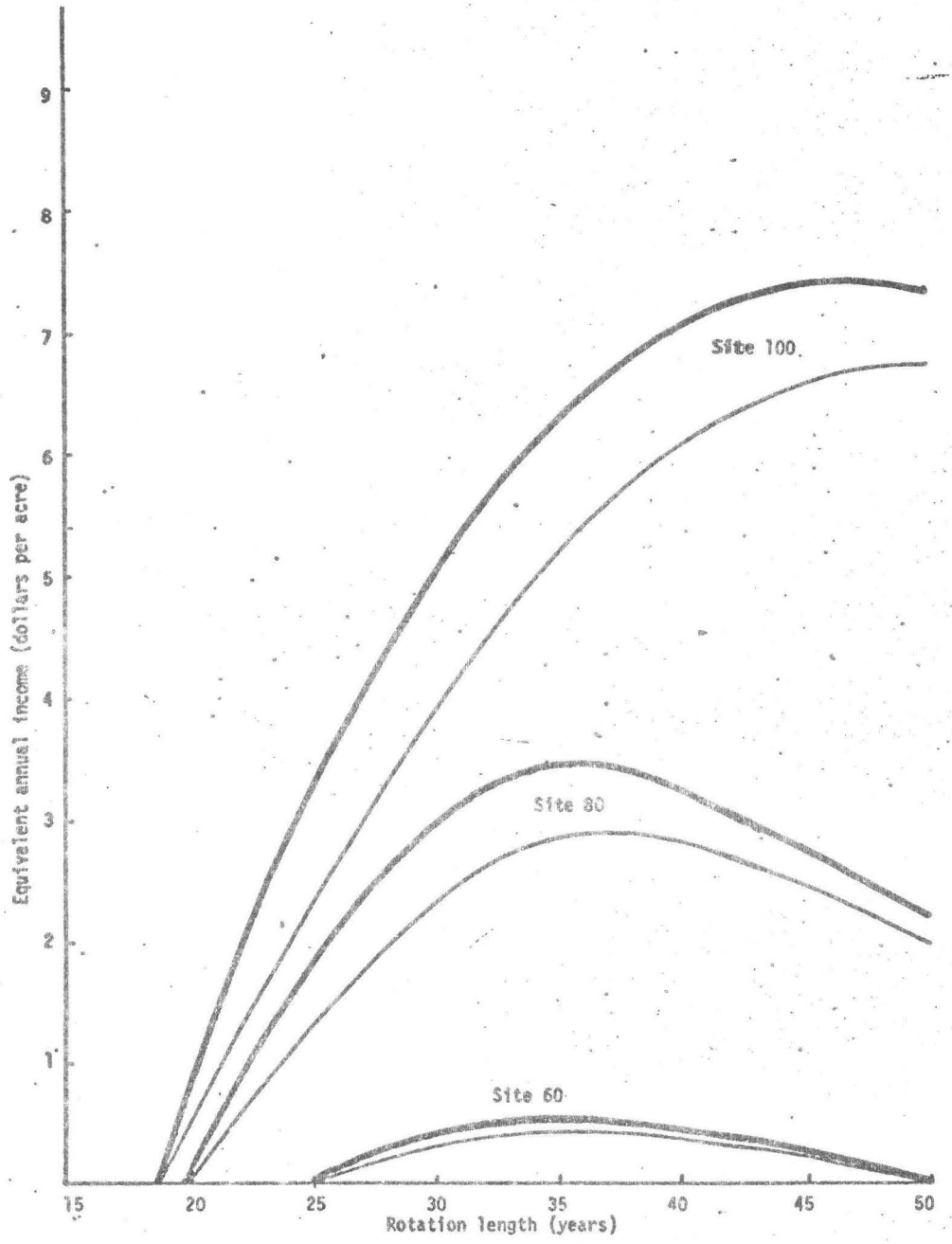
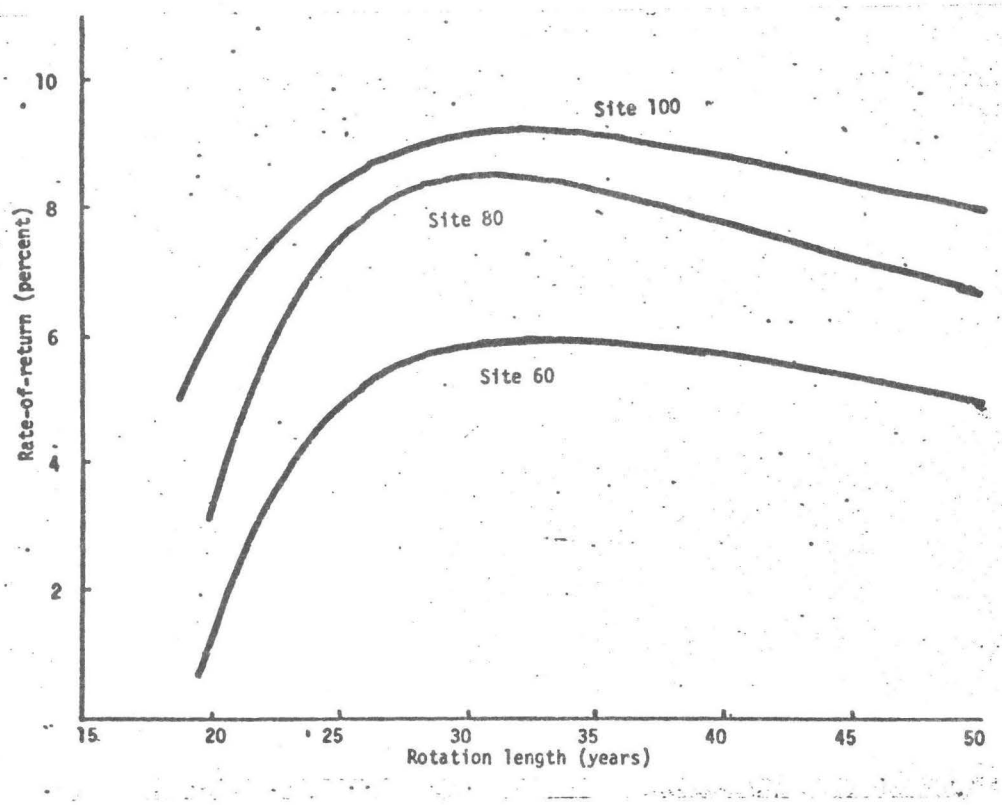


Figure 10.6--Rates-of-return from management level II--on cutover land--low site preparation--by rotation length and site index.



The comparison of rates-of-return level II with those of level I are also revealing. The rates-of-return are substantially lower because of the additional capital invested in site preparation and controlled burning, and they are at a maximum for 5-year longer rotations.

In figure 10.5 the difference between the solid and dotted lines indicates the present value of future rotations expressed in equivalent annual income. This can be used to indicate the returns from allowing old fields to regenerate naturally followed by a regime of site preparation and controlled burning. Thus the returns for managing old fields under management level II is the sum of this difference plus the returns from the initial old field rotation at Management Level I.

For both cutover land and old field situations the expected financial returns and resource measures are summarized in table 10.2. This table presents the basic data for the regimes selected for level II for further study. Some notable changes are the increased levels of growing stock and yield per acre, but the harvest diameter is smaller because of increased competition. The detailed regimes are in Appendix II.

Though this level of management is far short of intensive timber management in terms of volume and certainty of returns, measures to control hardwood and assure regeneration are important for the economics of timber supply. Millions of acres in the South are cutover annually without any attempt to treat the land to improve regeneration. Despite favorable rates-of-return

Table 10.2--Data for alternatives in management level II selected for further simulation.

Criterion and item		Cutover Site 60	Cutover Site 80	Cutover Site 100	Old field Site 60	Old field Site 80	Old field Site 100
Annual income criterion							
Annual income	($s)	0.55	3.51	7.40	1.55	5.36	10.62
Rate of return	(%)	6.0	8.3	8.5	9.7	14.2	11.9
Harvest age	(yrs)	35.	35.	45.	35.	30.	45.
Harvest diameter	(in)	10.3	13.6	19.1	9.9	11.9	17.9
Avg pine yield	(cuft)	42.5	70.1	101.9	49.8	83.2	115.8
Avg pine grow stock	(cuft)	617.	1053.	2240.	676.	908.	2471.
Compromise criterion							
Annual income	($s)	*****	*****	6.33	1.54	4.40	8.82
Rate of return	(%)	*****	*****	9.1	10.8	15.4	15.3
Harvest age	(yrs)	*****	*****	35.	30.	25.	30.
Harvest diameter	(in)	*****	*****	16.9	9.1	10.6	14.8
Avg pine yield	(cuft)	*****	*****	106.0	49.7	80.8	126.8
Avg pine grow stock	(cuft)	*****	*****	1613.	519.	639.	1420.
Rate-of-return criterion							
Annual income	($s)	0.55	3.01	5.05	1.28	3.22	5.87
Rate of return	(%)	6.0	8.4	9.2	11.6	15.7	17.3
Harvest age	(yrs)	35.	30.	30.	25.	20.	20.
Harvest diameter	(in)	10.3	12.3	15.5	8.1	8.8	10.9
Avg pine yield	(cuft)	42.5	68.7	104.3	47.5	71.7	110.6
Avg pine grow stock	(cuft)	617.	813.	1253.	355.	367.	605.

from site preparation on cutover lands, a minority of small and medium sized owners make these efforts. Site preparation is a first step after harvest in any type of management, whether natural regeneration or plantation.

Management Level III: Control of variation in regeneration

Among the next steps a owner should consider in intensification of management are measures to correct for extremes of regeneration. These extremes, which occur with random probability and cannot be controlled by the owner, are:

1. Insufficient regeneration. Frequently too few pines become established, resulting in a spotty stand and insufficient use of the site. The pines in a very sparce stand tend to grow rapidly to large diameters but have extremely poor quality. The term "old field pine" indicates low quality, limby trees with poor taper. If sufficient pine seedlings do not become established by age 3 or 4, hardwood or brush regrowth generally eliminates the possibility of later improvement. The remedy is to destroy the stand by repeating the site regeneration and to hope for better regeneration the next time.

2. Superabundant regeneration. As mentioned in Chapter 5, as many as 250,000 trees per acre can seed in when weather conditions are ideal and seed fall is heavy. Though this may occur very infrequently, obtaining as many at 1500 to 2000 trees per acre is relatively common. Such stands suffer from intense crowding that reduces diameter (and even height) growth, delaying

the age at which the stand can be thinned or harvested. A high proportion of the growth is lost to mortality.

This condition can also be recognized early. Corrective action should start at age 2 or 3. The treatment recommended (Grano, 1970) is to mow, disk, or chop the stand in strips at right angles that leave 600 to 900 small patches of trees. Generally, only one tree will become dominant.

If such expenditures are to be made it would also be advantageous to intensify site preparation to the extent that the seedbed would be virtually as good as an open field and the hardwood impact would be substantially lowered.

Figures 10.8 and 10.9 and table 10.3 show the median results expected from this intensification. The results of much greater regeneration success increases the numbers of trees and decreases the diameter at any harvest age. The increased number of trees delays by 10 years a stand from reaching sawtimber size on size 80, compared to level II. Only do trees on site 100 land become of sufficient size for profitable sawtimber within 40 years. The effect causes rotation age for site 60 and 80 to be the same for both rate-of-return and annual income criteria. The detailed regimes are given in Appendix II.

Another improvement aspect of this treatment is that it increases the likelihood that regeneration will be so abundant that the stands stagnate and become merchantable only at uneconomic ages.

The simulation model simulated the results of rotations for a range of probability levels of regeneration results for

Figure 10.7--Annual incomes per acre from management level III--intensive site preparation--on cutover land--by rotation length and site index. (Single rotation income is shown by dotted lines, perpetual series income by solid lines.)

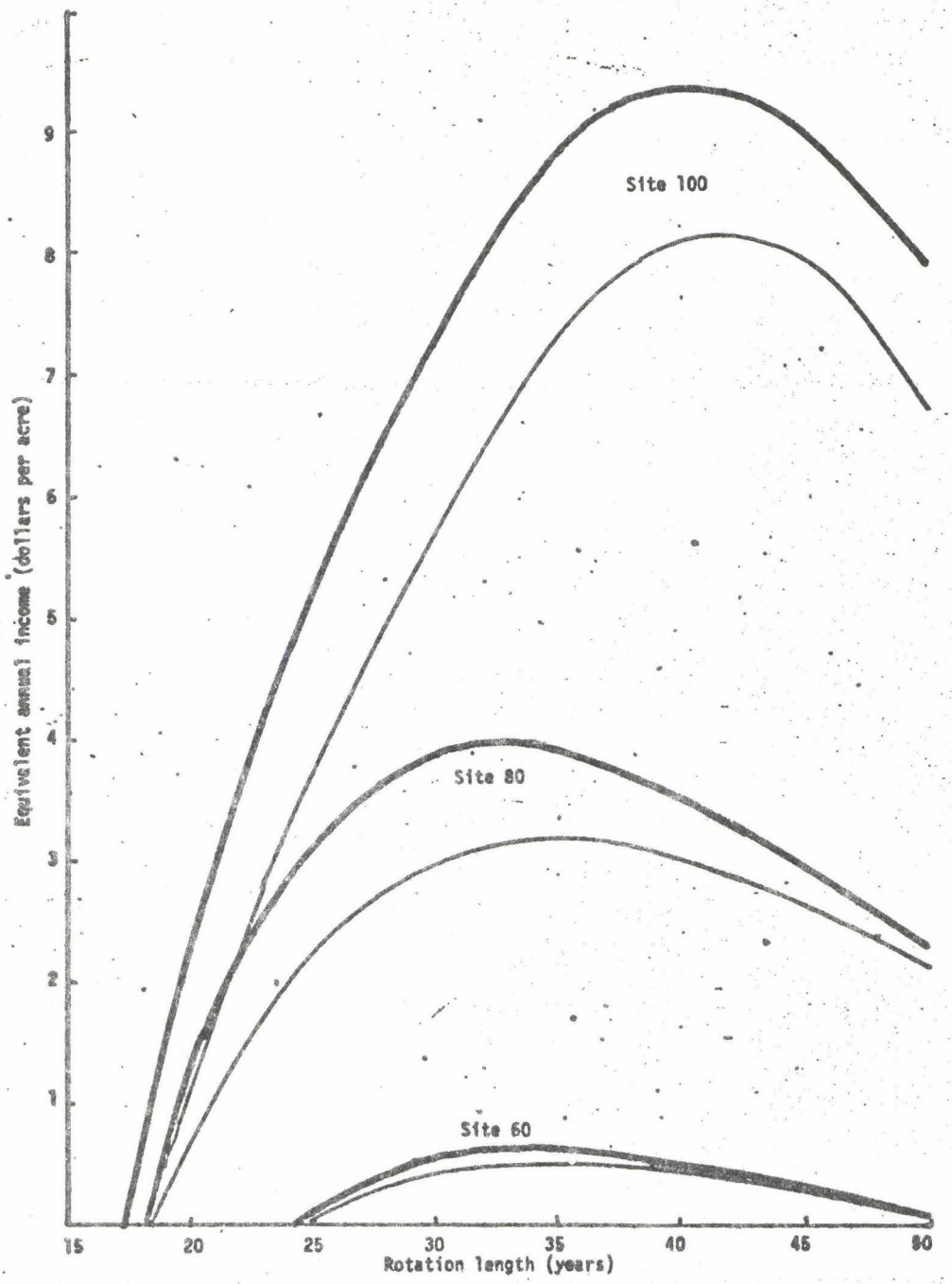


Figure 10.8--Rates-of-return from management level III--intensive site preparation--on cutover land--by rotation length and site index.

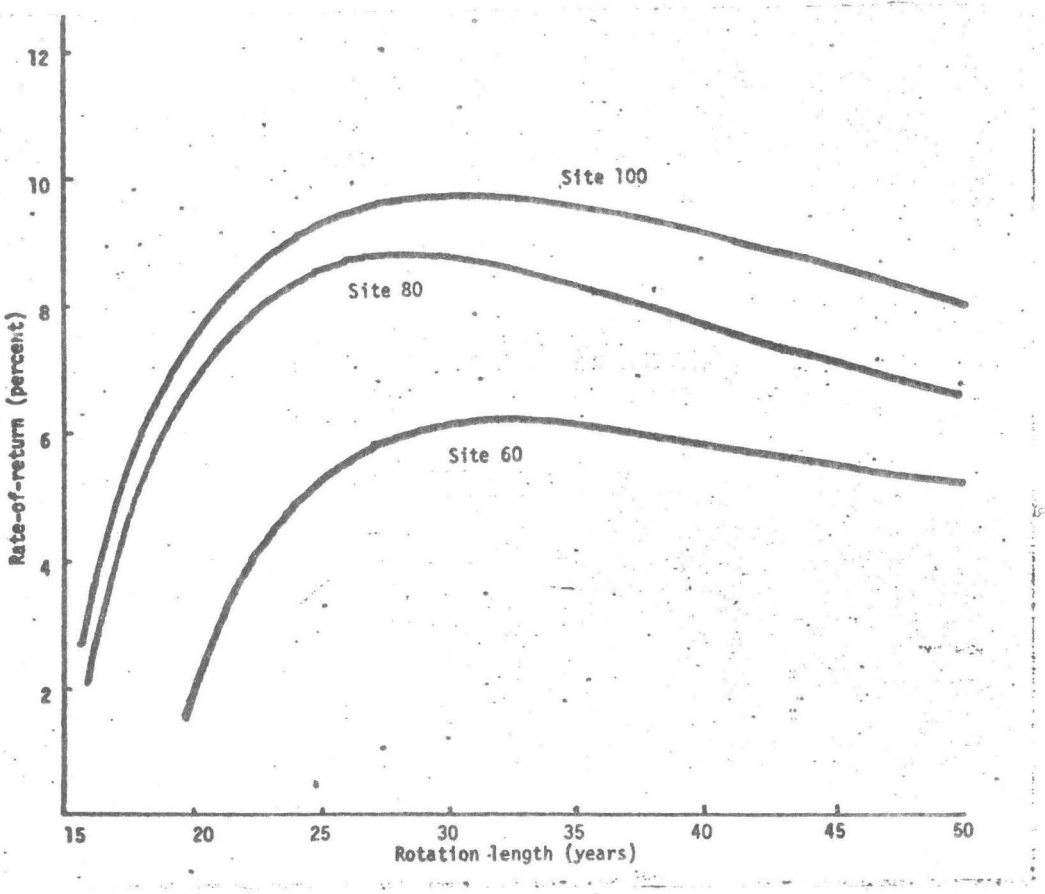


Table 10.3--Data for alternatives in management level III selected for further simulation.

Criterion and item		Cutover Site 60	Cutover Site 80	Cutover Site 100	Old field Site 60	Old field Site 80	Old field Site 100
Annual income criterion							
Annual income	($s)	0.62	3.89	9.42	1.58	5.48	9.43
Rate of return	(%)	6.0	8.2	9.1	9.8	14.3	10.7
Harvest age	(yrs)	35.	35.	40.	35.	30.	45.
Harvest diameter	(in)	9.5	12.4	16.5	9.9	11.9	17.9
Avg pine yield	(cuft)	49.2	81.7	120.8	49.8	83.2	115.8
Avg pine grow stock	(cuft)	743.	1289.	2348.	676.	908.	2471.
Compromise criterion							
Annual income	($s)	*****	3.89	8.65	1.58	4.55	9.31
Rate of return	(%)	*****	8.7	9.4	10.9	15.5	15.3
Harvest age	(yrs)	*****	30.	35.	30.	25.	30.
Harvest diameter	(in)	*****	11.3	15.4	9.1	10.6	14.8
Avg pine yield	(cuft)	*****	81.8	124.2	49.7	80.8	126.8
Avg pine grow stock	(cuft)	*****	1020.	1984.	519.	639.	1420.
Rate-of-return criterion							
Annual income	($s)	0.56	3.13	7.37	1.32	3.39	6.65
Rate of return	(%)	6.1	8.7	9.6	11.8	15.9	17.5
Harvest age	(yrs)	30.	25.	30.	25.	20.	20.
Harvest diameter	(in)	8.6	9.9	14.1	8.1	8.8	10.9
Avg pine yield	(cuft)	48.5	78.0	124.8	47.5	71.7	110.6
Avg pine grow stock	(cuft)	575.	722.	1578.	355.	367.	605.

cutover stands. Figure 10.9 shows the resulting equivalent annual incomes.[5/] The heavy lines indicate that equivalent annual incomes for all sites range from too few trees to yield satisfactory returns to far too many. The lines terminate where insufficient value is produced in 40 years for a merchantable cut. The characteristic peak occurs at the point where the increased volume is offset by reduced size and unit value of the trees.

Repreparation of site. As mentioned, an alternative the owner may choose if regeneration is not adequate is to destroy the reproduction by repreparing the site and hoping for better regeneration the second time (or third, or fourth). The question becomes: At what point is it more economic to sacrifice the present regeneration, the cost of a second site preparation, and the elapsed time?

Calculation of approximate breakeven points for each site compared the initial equivalent annual income for a range of probabilities less than .3 assuming that (a) the stand would not be reprepared, would be cut at age 35, and average regeneration results for subsequent rotations would be realized, and (b) the stand would be reprepared at age 5 at the same cost as the initial treatment, and that average results would occur on the delayed first rotation of 30 years, and on the subsequent 35-year rotations

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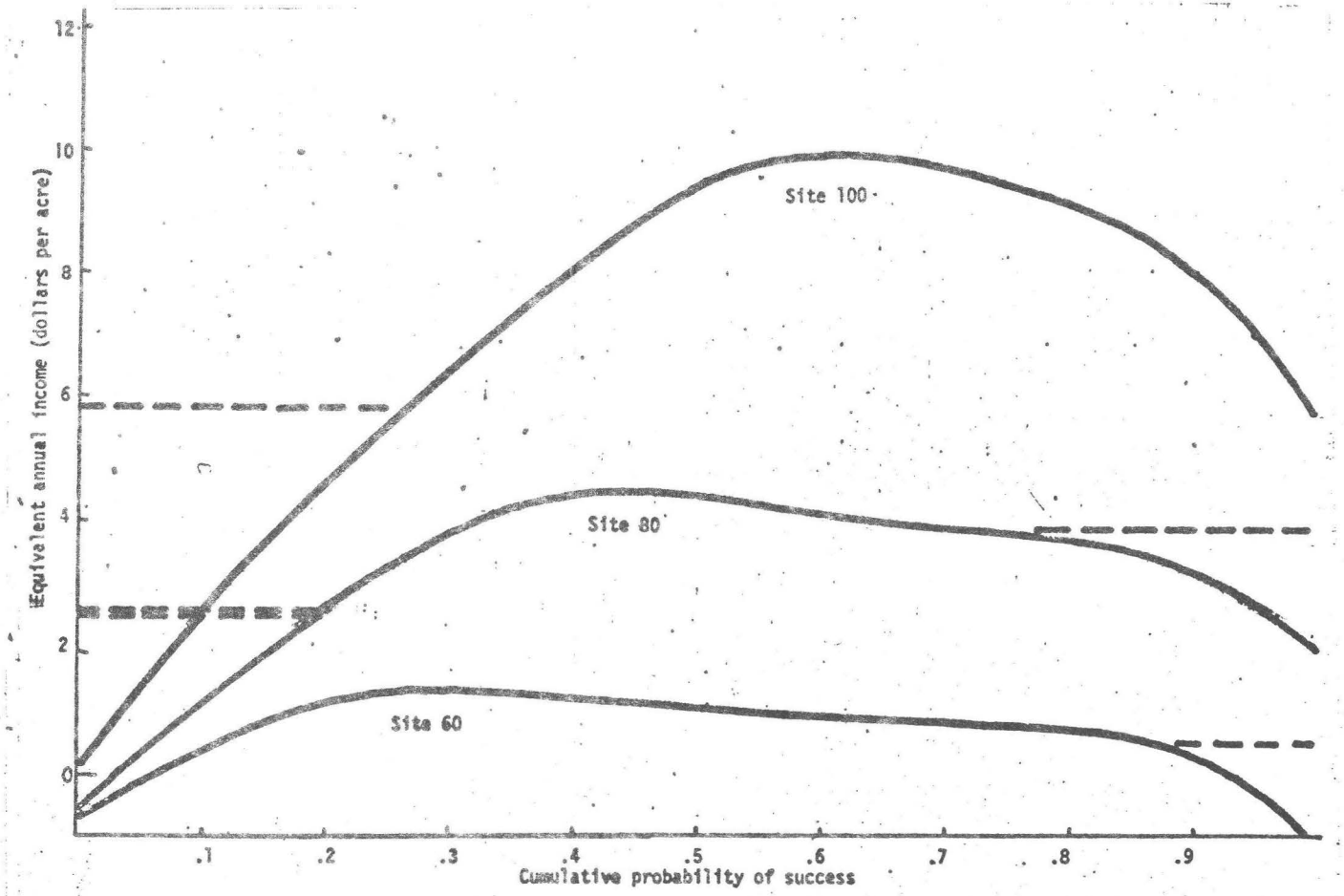
5/To conform with the other figures in this Chapter the graph shows the cumulative probability distribution of regeneration, developed in Chapter 5, on the horizontal axis and the measure of financial return on the vertical. This is not a graph of the probability of financial returns.

Figure 10.9--Annual incomes per acre for management level III--intensive site preparation--by probability of regeneration and site index. Levels at which repreparation and precommercial thinning yield more income are shown by dotted lines.



thereafter. The calculations were based on the viewpoint at year 0, even though the decision would be made at year 5. The data for p = .05 are shown in table 10.4. The initial treatment costs and the subsequent rotations net out from the comparisons so that all that would be necessary would be a comparison of the remainder of the first rotation. The full comparison was made so that the net incomes could be compared with the other alternatives.

The results show that unless the first rotation promises a return of $-.19 for site 60, $2.58 for site 80, and $5.81 for site 100, the tract should be reprepared. This corresponds to roughly 100 established trees at age 10 or 200 trees per acre at age 2 or 3. At this stage the breakeven point can only be approximate. The breakeven points would be unlikely to shift with changes in the relationship between sawtimber and pulpwood prices since the trees will generally be of sawtimber size. The probability levels associated with this density are shown in the next section.

Precommercial thinning. At the other end of the regeneration probability distribution are stands of dense crowded trees that will grow slowly and have a delay in reaching merchantability. The annual incomes associated with these stands are also shown in figures 10.8 and 10.9. The annual income drops off rather sharply, and finally drops to a negative value when the stands no longer become merchantable at age 35. In practice they would probably be kept until they were merchantable for pulpwood.

Table 10.4--Illustrative comparisons of equivalent annual incomes from repreparation of inadequate regeneration and precommercial thinning of superabundant regeneration.

Present value for:	Repreparation (p = .05)			Thinning (p = .95)		
	Site 60	Site 80	Site 100	Site 60	Site 80	Site 100
Treatment						
Initial site preparation	$- 15.20	$- 22.70	$- 30.20	$- 15.20	$- 22.70	$- 30.20
Treatment at age 5 or 2	- 11.90	- 17.78	- 23.65	- 6.34	- 6.34	- 6.34
Other costs - 1st rotation	- 16.79	- 21.03	- 25.03	- 20.40	- 24.25	- 27.54
Harvest at investment age	37.02	71.55	168.00	50.25	118.52	185.51
Net-1st rotation	- 6.87	37.66	89.19	8.31	65.23	121.43
Subsequent rotations	3.05	13.99	26.96	3.05	13.98	26.95
Total	- 3.82	51.64	116.14	11.36	79.70	148.38
Equivalent annual income	- .19	2.58	5.81	.57	3.96	7.42

(continued)

Table 10.4--Illustrative comparisons of equivalent annual incomes from repreparation of inadequate regeneration and precommercial thinning of superabundant regeneration. (continued)

Present value for:	Repreparation (p = .05)			Thinning (p = .95)		
	Site 60	Site 80	Site 100	Site 60	Site 80	Site 100
No treatment						
Initial site preparation	- 15.20	- 22.70	- 30.20	- 15.20	- 22.70	- 30.20
Other costs 1st rotation	- 17.20	- 21.67	- 26.15	- 18.51	- 22.80	- 27.21
Harvest at age 30	25.51	37.99	59.01	28.33	83.40	172.35
Net-1st rotation	- 6.89	- 6.38	2.66	- 5.38	- 37.90	114.94
Subsequent rotations	3.05	13.98	26.96	3.05	13.98	26.95
Total	3.84	7.60	29.62	2.32	51.88	141.89
Equivalent annual income	= .19	.38	1.48	= .12	2.59	7.09

At p = 95, precommercial thinning gives a higher annual income for all site classes. The cumulative probability levels at which it would prove economical are:

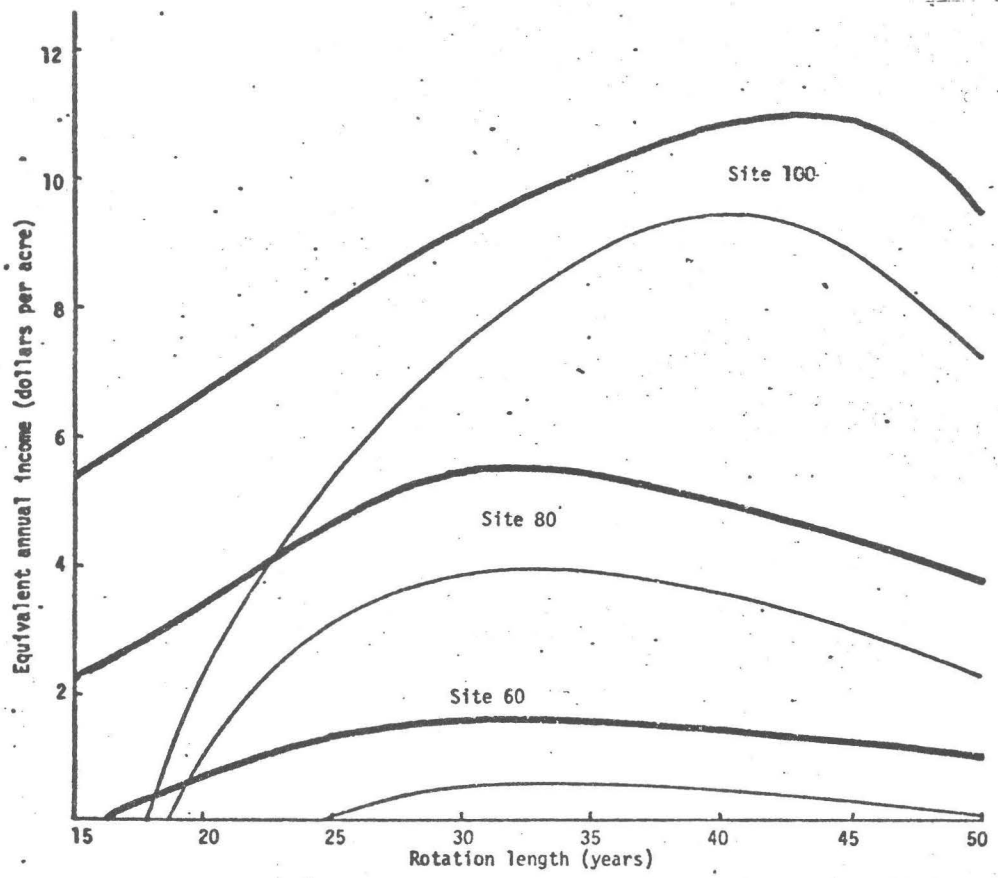
	Repreparation	Precommercial thinning
Site 60	.05	.85
Site 80	.20	.70
Site 100	.25	.95

This breakeven point would be highly sensitive to the ratio between lumber and pulpwood prices. If the ratio increased in favor of lumber, the average expected value would rise relative to the returns from very dense stands considered for precommercial thinning.

Repreparation and precommercial thinning has no effect on median yields. Its primary effect is to reduce the disparity between median and average yields and reduce the standard error of those yields. The effect of repreparation and precommercial thinning will be shown by simulation of the standard error of annual incomes in Chapter 11.

Figure 10.10 shows the equivalent annual incomes that would reduce from management level III at median regeneration success on old field sites. The distinctive shape results from the assumption that the old field rotation would be followed by the best length of rotation on cutover land, to which the old field would revert after the first rotation. The rates-of-return curves have the same shape at those in figure 10.8.

Figure 10.10--Comparison of annual incomes from management level III--intensive site preparation--on old field land (solid lines) and cutover land (dotted lines) by rotation length and site index.



Management Level IV: To thin or not to thin.

The foregoing levels of management have progressively increased the certainty of natural regeneration but have also increased the probability that the stands may be too dense to yield large sized timber in reasonably short rotations. The next increase in management intensity is to thin natural stands after they reach minimum merchantable size and if basal area stocking exceeds a desired level. Since they yield immediate returns, commercial thinnings might initially seem to be automatically a desired practice. Thinnings, however, have both favorable and unfavorable effects.

The advantage of thinnings are: (a) part of the yield is harvested early, bringing in valuable returns, (b) total yields in cubic feet are increased because trees are utilized that would die from suppression as the stands become increasingly well stocked, (c) growth during the remaining portion of the rotation is concentrated on the selected trees left.

The major disadvantages are: (a) Thinnings sell at lower values per cubic foot than if the wood was held for a clearcut harvest, because thinned tree size is small and volume cut per acre is light, (b) thinning exposes stands to infection by the Fomes root rot and infestation by bark beetles, especially the engraver and black turpentine beetles.

A number of merchantability factors limit commercial thinning possibilities. Thinnings of trees averaging less than 5 inches in diameter cannot be sold because pulpmills require pulpwood

of minimum bolt diameter and costs of harvesting are high. The loss in cubic volume from low utilization, however, may even reduce the returns to the owner from thinnings less than 6 to 7 inches. A second limitation is that cuts of only a few trees per acre, even if of sawtimber size, are also unsaleable and have relatively little influence on stand growth. In this study no cuts of less than 10 square feet basal area per acre were considered.

Numerous thinning pattern policies are feasible. As mentioned in Chapter 3, there are at least four important decision variables over which the owner has at least partial control. The first two are strongly related:

1. Age of first commercial thinning. The stand may be thinned just as soon as it is feasible or thinning may be delayed.

2. Severity of thinning, usually stated in terms of basal area left remaining. Timing and severity of first thinning depends upon stand stocking and site index, and desired reserve basal area. Poor sites have smaller trees and less basal area than stands of similar age on better sites. Trees on overstocked stands are smaller than those less well stocked though the basal area may be substantially larger.

Simulation model runs indicated the earliest date that could be considered for thinning for 10 levels of probability of regeneration and three site index classes. These are shown in table 10.5. The pattern of ages and dollar earnings on the first thinning confirm these general hypotheses. On poor sites,

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Table 10.5--Minimum ages that natural stands of management level II meet thinning criteria.

Cumulative regeneration probability	Site 60 Thinning level			Site 80 Thinning level			Site 100 Thinning level		
	60	70	80	70	80	90	80	90	100
.05	30	-[1/]	-	30	-	-	30	30	-
.15	25	30	-	25	30	-	25	30	30
.25	25	25	30	25	25	30	25	25	30
.35	20	25	30	20	25	25	20	25	25
.45	20	20	25	20	20	25	20	20	25
.55	20	20	25	20	20	25	20	20	25
.65	20	20	25	15	20	20	15	20	20
.75	20	20	25	15	20	20	15	20	20
.85	20	20	25	20	20	20	15	15	20
.95	25	25	25	20	20	20	15	15	20

1/ Dash indicates the stand does not reach sufficient basal area before age 35.

thinnings are not feasible or are delayed on poorly stocked tracts of all sites, particularly if high reserve basal areas are desired. Stands are able to be thinned on high site 100 lands at early ages if relatively low reserve basal areas are desired. On these lands high levels of stocking produce overcrowded stands that retard growth and delay age of first thinning.

3. Frequency of repeated thinnings. A number of simulation runs using both 5- and 10-year thinning frequencies showed that regimes in which stands were thinned every 10 years produced larger equivalent annual incomes than stands thinned every five years. The exceptions were those stands that could be thinned twice at 5-year intervals before they reached sawtimber size. This rule of thumb confirms conventional wisdom and was employed in the thinning simulations.

4. Severity of repeat thinnings. Some foresters recommend gradually increasing the basal area reserved in thinning as the stands grow older. Trial simulations indicated that this has little effect on equivalent annual income. The severity of initial thinning seems the controlling factor in financial returns. The simulations made for this study maintained the same basal area throughout each regime.

Simulations were run for each of the three site index levels at median levels of stocking probability. The rates of return and annual incomes are shown in figure 10.11 and 10.12. Only those thinning levels that result in equivalent annual incomes that are reasonably close to maximum are shown. Basal area

Figure 10.11--Annual incomes per acre from management level IV--thinned plantations--on cutover land, by rotation length, reserve basal area level, and site index. Incomes from unthinned stands for each site index are shown by dotted lines.

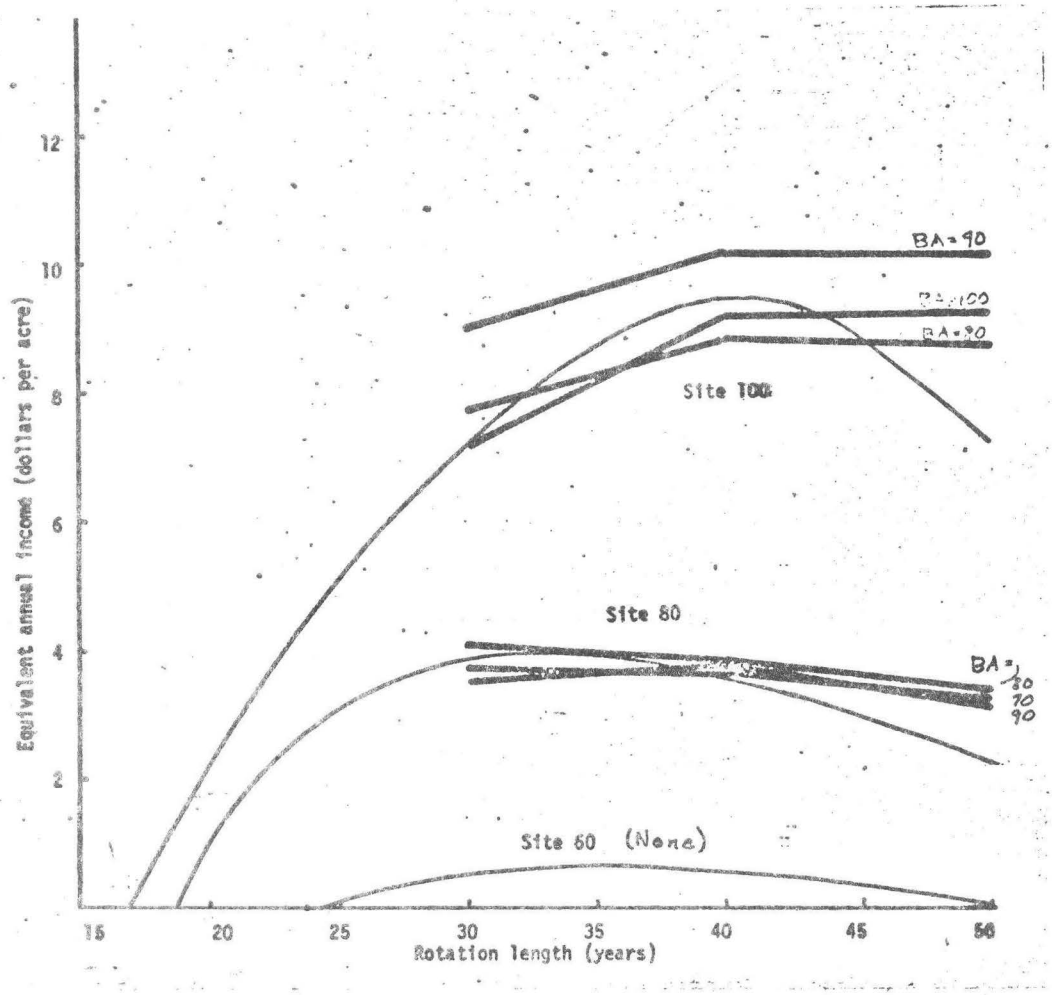
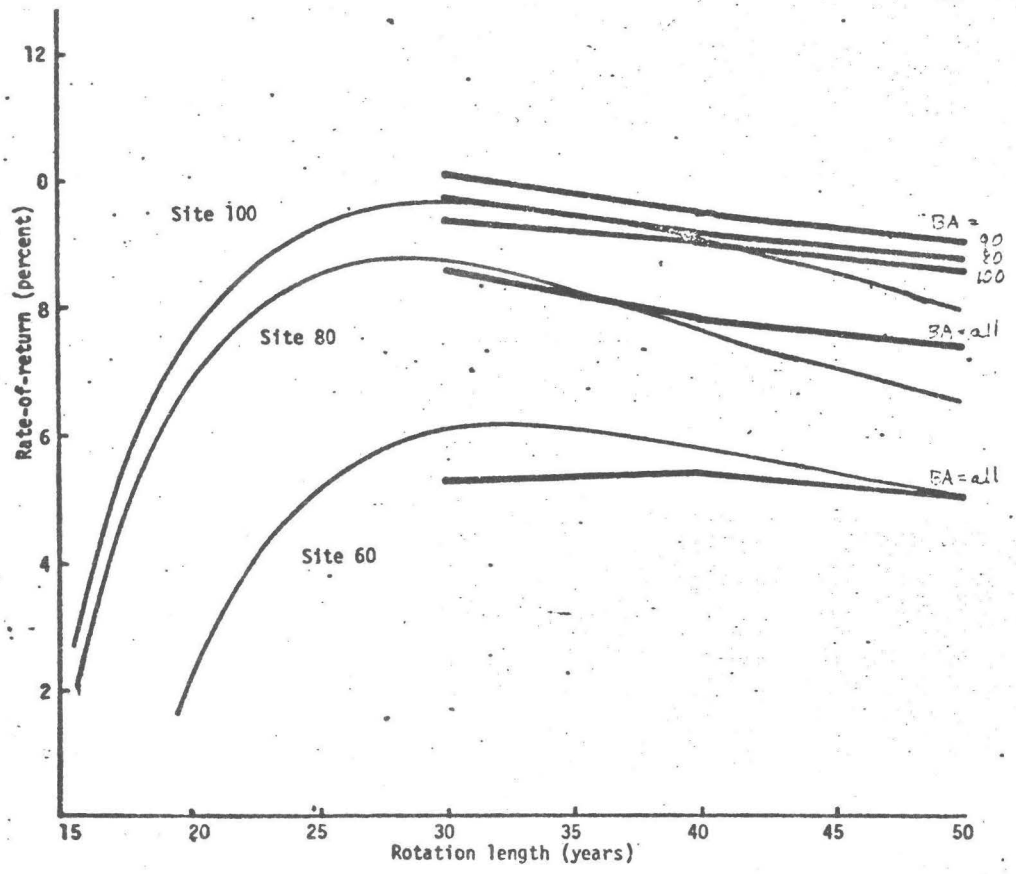


Figure 10.12--Rates-of-return from management level IV--thinned natural stands--on cutover land--after intensive site preparation treatment--by rotation length, reserve basal area level, and site index.



guides of 90 or more do not seem reasonable for site 60 and those of 70 or less are not competitive for site 100 lands.

For site 60, thinning does not seem to yield more returns than unthinned stands. No alternatives will be further studied. The loss in values from small sales is not offset by greater cubic foot yields. The major product in any case is still pulpwood sized timber. For site 80, the best stand density appears to be 80 square feet, though 70 square feet seems nearly as good and may be most economical with higher lumber prices. Best age seems to be only 30 years. In effect thinning seems to increase harvest diameters so that they reach small sawtimber early. For site 100 the best stand density at assumed prices is 100 square feet basal area and the best rotation age appears to be 40.

For both site 80 and 100 the regimes selected were 30 and 40 years at the best basal area levels and 40 years at the next lower basal area (table 10.6). If the owner anticipates that lumber and sawtimber prices will increase faster than pulpwood prices, 40-year rotations would allow him to reap the benefit from such price rises. The regime details are in Appendix II.

In addition thinning timber stands sharply reduces the significance of rotation age or length of timber holding period since both the annual income and rate of return curves are quite flat. This gives increased flexibility to timber management planning and partially frees the owner from dependence on selling

Table 10.6--Data for alternatives in management level IV selected for further simulation.

Criterion and item		Cutover Site 60	Cutover Site 80	Cutover Site 100	Old field Site 60	Old field Site 80	Old field Site 100
Annual income criterion							
Annual income	($s)	0.34	4.29	10.18	1.35	5.80	11.20
Rate of return	(%)	5.5	8.3	9.6	8.8	12.3	13.7
Harvest age	(yrs)	40.	35.	40.	35.	35.	40.
Harvest diameter	(in)	10.7	12.7	17.7	10.1	13.4	18.8
Avg pine yield	(cuft)	51.5	90.7	147.2	52.8	91.2	146.4
Avg pine grow stock	(cuft)	795.	1234.	2027.	642.	1113.	1870.
Compromise criterion							
Annual income	($s)	*****	*****	8.51	1.19	5.34	10.37
Rate of return	(%)	*****	*****	9.5	9.3	13.2	15.3
Harvest age	(yrs)	*****	*****	35.	30.	30.	30.
Harvest diameter	(in)	*****	*****	16.5	9.5	11.9	14.9
Avg pine yield	(cuft)	*****	*****	138.2	50.1	83.2	146.0
Avg pine grow stock	(cuft)	*****	*****	1778.	495.	909.	1393.
Rate-of-return criterion							
Annual income	($s)	0.34	3.63	9.00	1.04	4.45	8.07
Rate of return	(%)	5.5	8.3	10.1	9.9	14.1	15.5
Harvest age	(yrs)	40.	30.	30.	25.	25.	25.
Harvest diameter	(in)	10.7	11.4	13.9	8.1	10.6	13.1
Avg pine yield	(cuft)	51.5	81.8	145.1	47.5	80.8	123.7
Avg pine grow stock	(cuft)	795.	1020.	1570.	355.	639.	1015.

timber during any particular market period. Thinning does not, however, tend to lengthen the rotation age, as the conventional wisdom seem to indicate.

Figure 10.13 shows annual income data for old field stands. Thinning raises incomes slightly but changes incomes hardly at all for site 80, and decreases them for site 60. A major effect may be from the sale of timber at small sizes as thinnings that could be sold as larger and more valuable timber later. The fixed cost incurred in each sale has negligible effect. The effects on rates-of-return are similar.

Analysis of plantation management

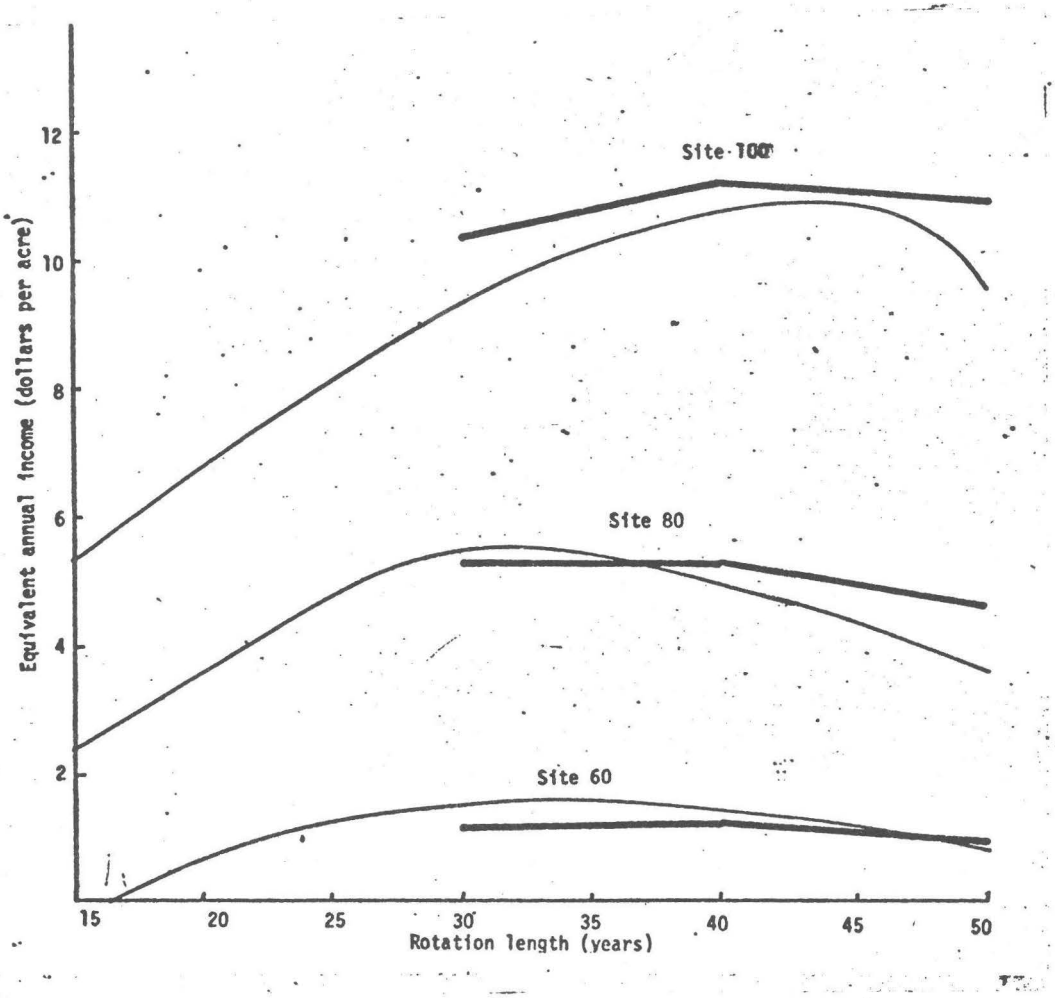
The replacement of natural stands with planted stands is a basic change in management of southern pines. Even though the species, and even the genetic stock, may be similar, biological functions of growth and development of plantations are quite different from natural stands. Chapter 5 discusses these differences and the yield functions associated with them.

Management level V: Unthinned plantations

The simplest plantation management includes site preparation, planting, but no thinning until harvest. The initial trials of this level assume a rather wide spacing of 10 by 9 feet or 500 trees per acre. This is a recent recommendation for management in the South.

The simulations assume an intensive site preparation treatment

Figure 10.13--Comparison of annual incomes per acre from management level IV--thinned natural stands--on old fields--by rotation length, reserve basal area level, and site index. Incomes from unthinned stands for each site index are shown by dotted lines.



on cutover land. Planting can be done either by hand or machine, whichever is cheaper. In addition, cutover and converted land also often require a herbicide spray at age 3 to assure control of hardwoods.

Since plantations on cutover or converted land are somewhat slower in growth than the plantations on which the yield functions are based, plantation age is reduced by one year. In addition, on pine cutover land actual planting has to be delayed usually one year while populations of Pales weevils in the stumps subside.

In unthinned plantation management there are essentially two management decisions: (a) length of rotation age and (b) number of seedlings planted.

A major factor in the management of unthinned plantations is that all of the trees start out with about the same competitive advantage. Consequently mortality is much lower than in natural stands and large numbers of trees persist for many years. Average diameters are smaller than in natural stands of similar age and density. None of the rotations develop trees that are well into the sawtimber size class. Therefore unit values do not develop that would give advantage to longer rotations.

Figures 10.14 and 10.15 show equivalent annual incomes and rates-of-return for different rotation ages at 500 trees per acre. At no rotatior age does site 60 land show a positive return. Site 80 returns are in the same neighborhood as the returns for natural stands on the same site--$5.00 an acre per

Figure 10.14--Annual incomes per acre from management level V--unthinned plantations--on cutover land, by rotation length and site index. (Single rotation incomes are shown by dotted lines, from perpetual series of rotations by solid lines.)

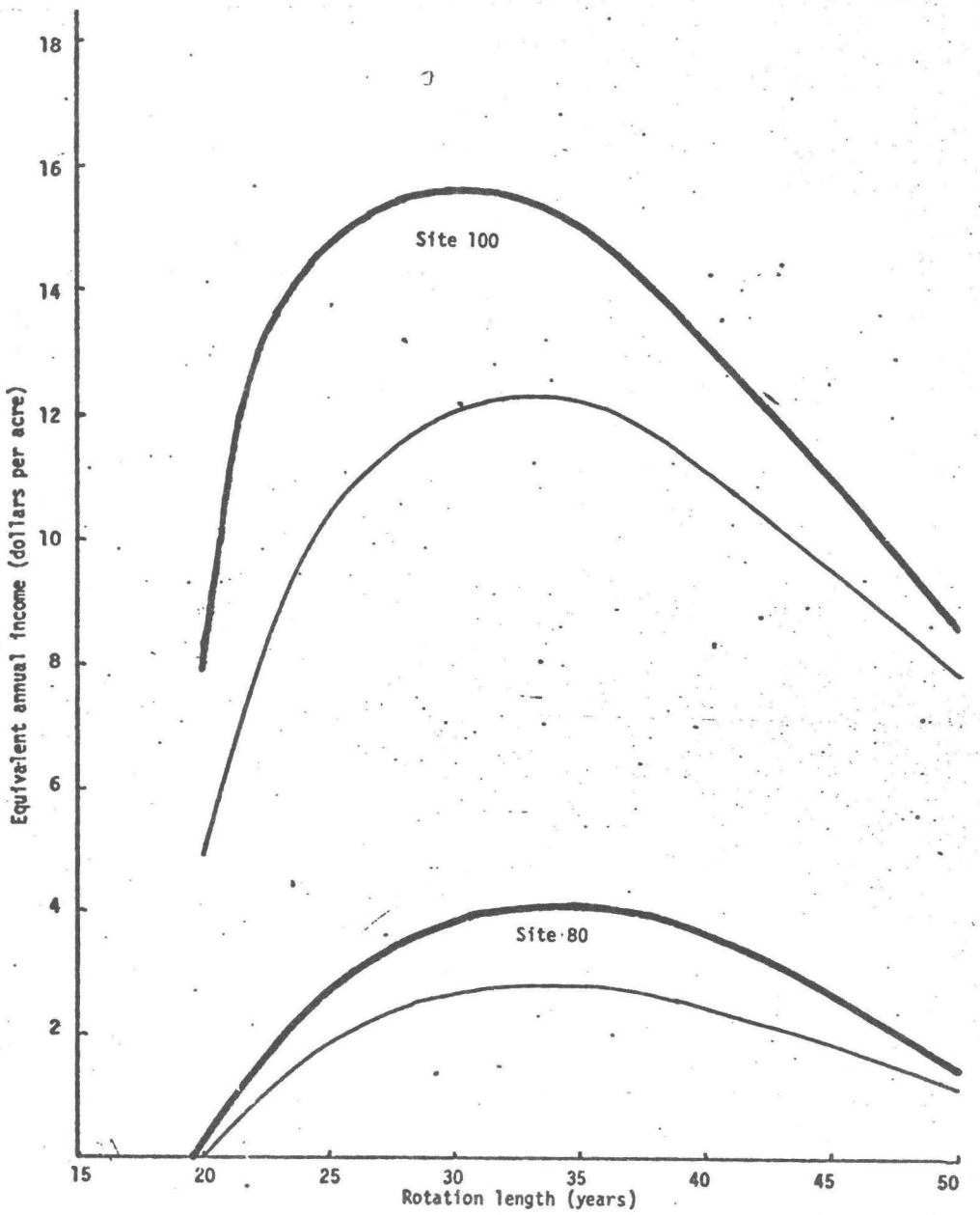
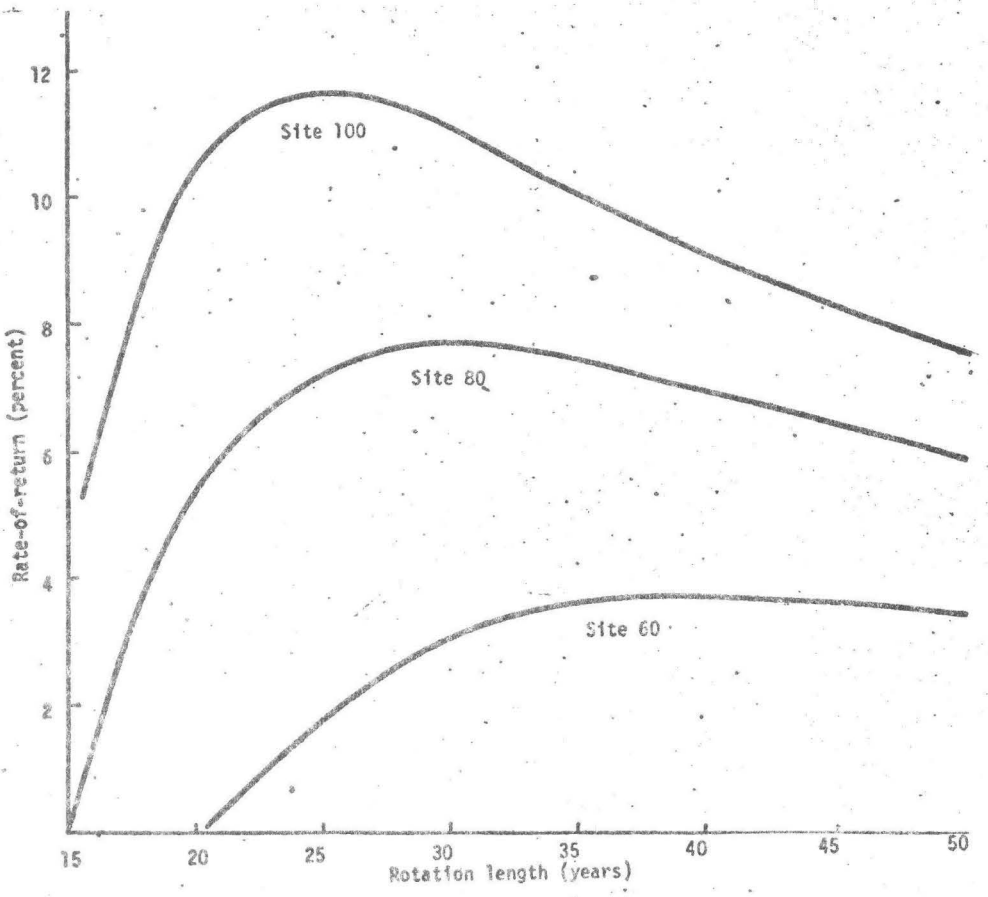


Figure 10.15--Rates-of-return from management level V--unthinned plantations--on cutover land, by rotation length and site index.



year. On site 100 land the best annual incomes increase by nearly 50 percent, to about $16 an acre per year.

On site 80 land the 35-year rotation is marginally better than the 30 year rotation. The 30-year rotation is clearly the best on site 100 land.

The effect of number of seedlings per acre on yields, as mentioned in Chapter 5, is significant. Within the range now commonly planted in the South, cubic foot yields continue to rise with number of seedlings. Though somewhat at odds with the conventional wisdom, the evidence from the Lenhart-Clutter (1971) yields is clear.

Since the diameters do not reach sawtimber size except for very wide plantations, the additional trees do not reduce unit values significantly. Thus the equivalent annual incomes continue to rise up to 1200 seedlings per acre. The returns are presented in figure 10.16 for site 80 and site 100. At no level of seedlings per acre, are plantations rewarding on site 60 land.

The regimes selected for further study in Chapter 11 are shown in table 10.7. The intermediate regime is specified as 1000 trees at rotation age 30 for both land productivity classes. Regime details are shown in Appendix II.

Plantation management at level V is suitable both for old fields, and for hardwood land converted to pine management by clearing the hardwoods with heavy equipment. The conversion process leaves the land in nearly a cleared land condition.

Figure 10.16--Annual incomes per acre from management level V--on cutover land--by number of seedlings per acre and site index.

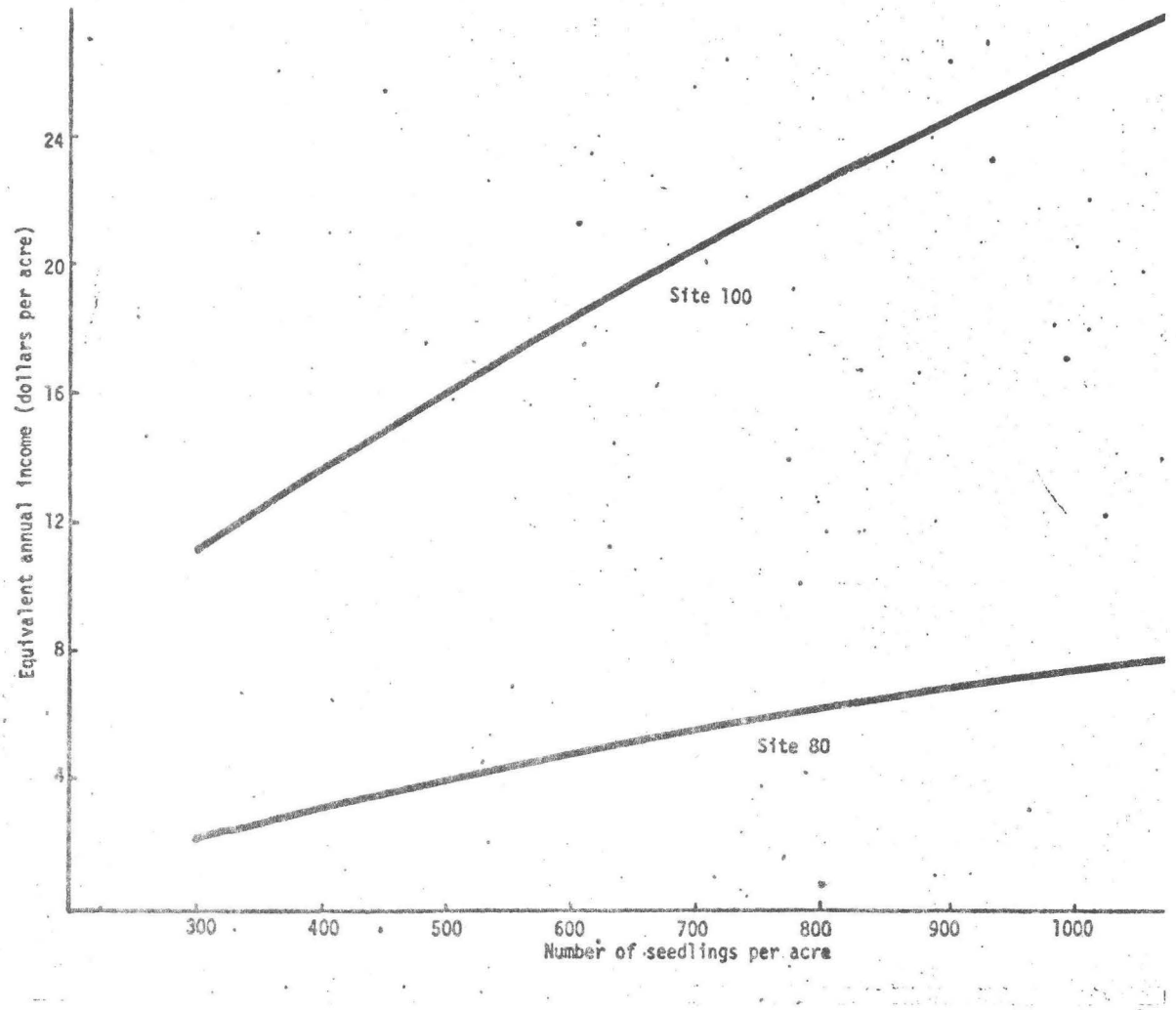


Table 10.7--Data for alternatives in management level V selected for further simulation.

Criterion and item		Cutover Site 60	Cutover Site 80	Cutover Site 100	Old field Site 60	Old field Site 80	Old field Site 100	Hardwoods Site 60	Hardwoods Site 80	Hardwoods Site 100
Annual income criterion										
Annual income	($s)	*****	8.42	17.40	*****	4.82	17.44	*****	3.87	16.40
Rate of return	(%)	*****	9.0	10.7	*****	8.0	10.9	*****	6.7	10.4
Harvest age	(yrs)	*****	40.	40.	*****	30.	30.	*****	30.	25.
Harvest diameter	(in)	*****	16.2	19.5	*****	8.8	10.3	*****	8.8	9.7
Avg pine yield	(cuft)	*****	138.6	237.9	*****	125.3	228.7	*****	125.3	220.7
Avg pine grow stock	(cuft)	*****	1508.	2570.	*****	1377.	2648.	*****	1377.	1940.
Compromise criterion										
Annual income	($s)	*****	6.63	15.20	*****	*****	*****	*****	*****	*****
Rate of return	(%)	*****	8.5	10.5	*****	*****	*****	*****	*****	*****
Harvest age	(yrs)	*****	40.	40.	*****	*****	*****	*****	*****	*****
Harvest diameter	(in)	*****	17.8	20.9	*****	*****	*****	*****	*****	*****
Avg pine yield	(cuft)	*****	130.7	227.9	*****	*****	*****	*****	*****	*****
Avg pine grow stock	(cuft)	*****	1355.	2364.	*****	*****	*****	*****	*****	*****
Rate-of-return criterion										
Annual income	($s)	*****	7.57	15.68	99.99	4.16	17.35	99.99	3.87	16.40
Rate of return	(%)	*****	9.3	11.2	*****	8.1	11.9	*****	6.7	10.4
Harvest age	(yrs)	*****	30.	30.	*****	25.	25.	*****	30.	25.
Harvest diameter	(in)	*****	12.4	14.8	*****	8.4	9.8	*****	8.8	9.7
Avg pine yield	(cuft)	*****	139.5	244.5	*****	118.2	220.7	*****	125.3	220.7
Avg pine grow stock	(cuft)	*****	1128.	2000.	*****	9808.	*****	*****	1377.	1940.

Spraying with herbicides reduces the regrowth of hardwood sprouts and prevents them from overtopping the pine.

Figure 10.17 shows the annual incomes per acre that would result from unthinned pine plantations on these land types. The difference between the two lines is merely the amortized cost of the initial conversion treatment. Both annual income and rate-of-return patterns resemble strongly those from cutover land.

Management level VI: Thinned plantations

The next logical step in the sequence of management intensity is thinning of plantations. The same assumptions were employed as in the unthinned plantations: (a) Intensive site preparation, (b) spraying at age 2 to control hardwoods, and (c) controlled burning.

In addition the same assumptions governed the thinning procedures as in thinned natural stands: (a) thinnings must average 6.0 inches diameter, (b) the basal area removed must be at least 10 square feet basal area, and (c) thinnings must not be closer than 10 years apart after the stand reaches sawtimber size.

The results of the simulations are shown in figures 10.18 and 10.19. Only a few of the plantation regimes on site 60 land return the minimum 5 percent guiding rate. Site 60 is therefore dropped from consideration at this management level. Both site 80 and 100 have regimes that return greater annual incomes than from unthinned stands.

Figure 10.17--Comparison of annual incomes per acre from management level V--unthinned plantations--on open field land and converted hardwood land, by rotation length and site index.

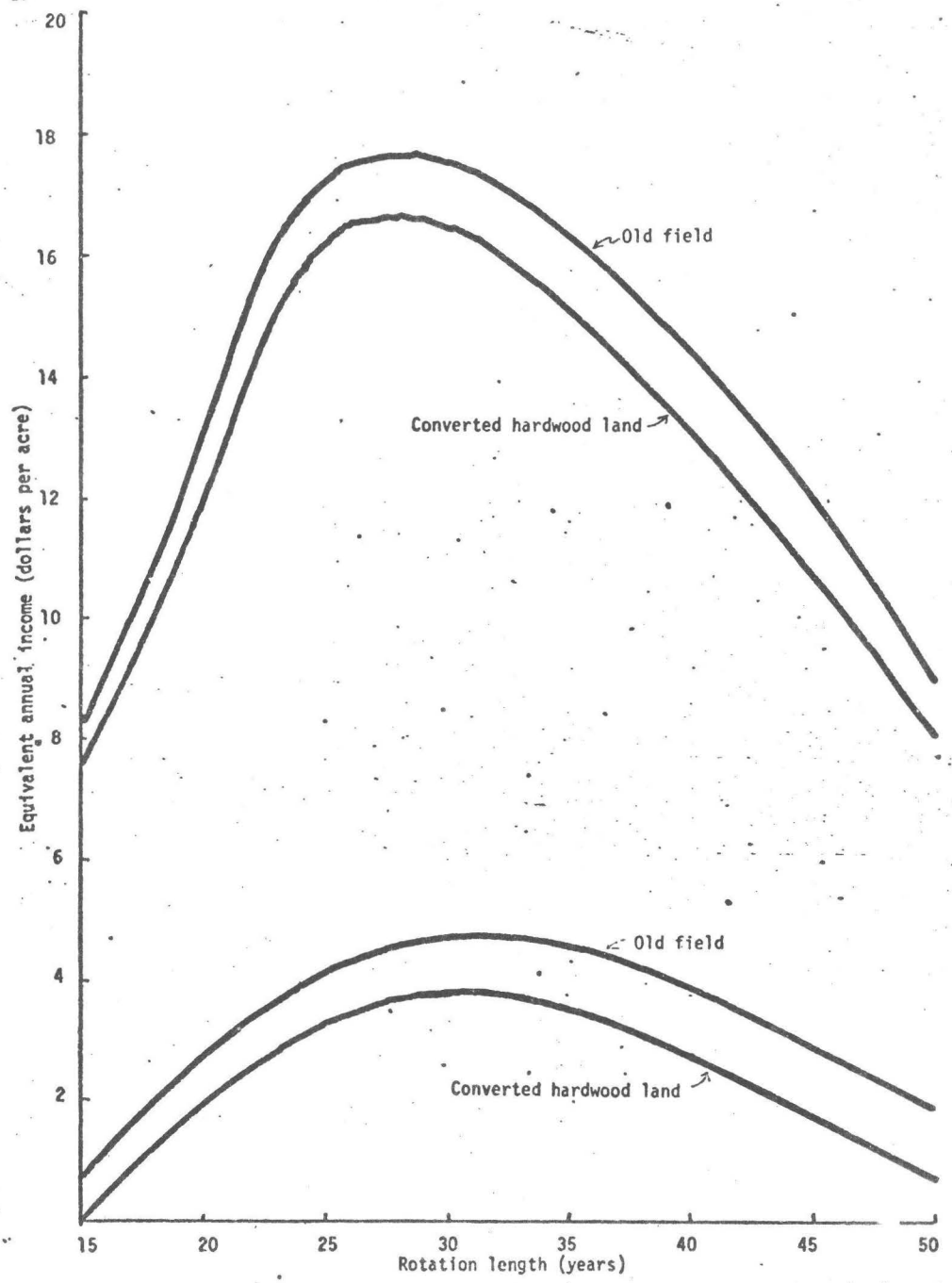


Figure 10.18--Annual incomes per acre from management level VI--thinned plantations--on cutover land by rotation length, reserve basal area level, and site index.

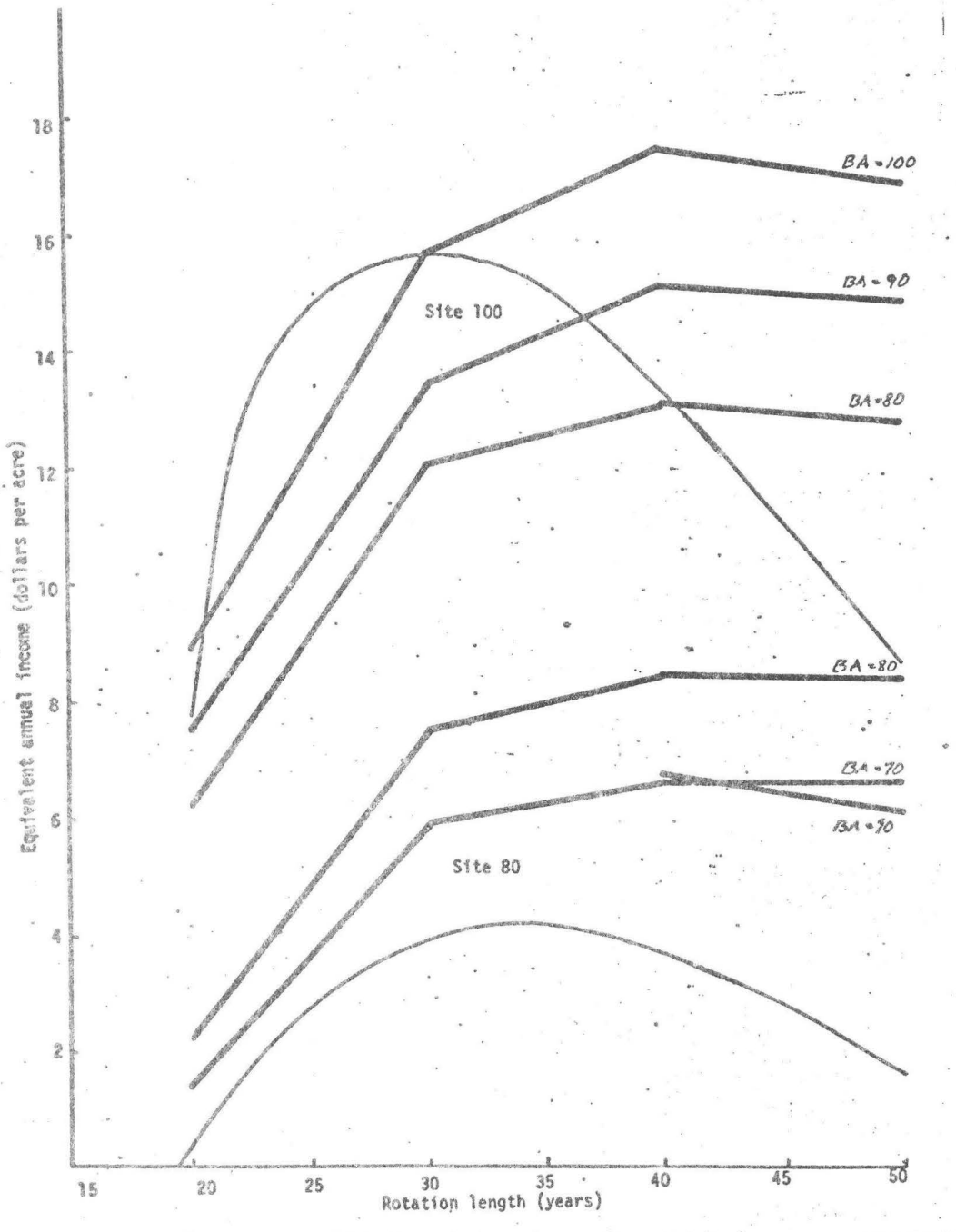
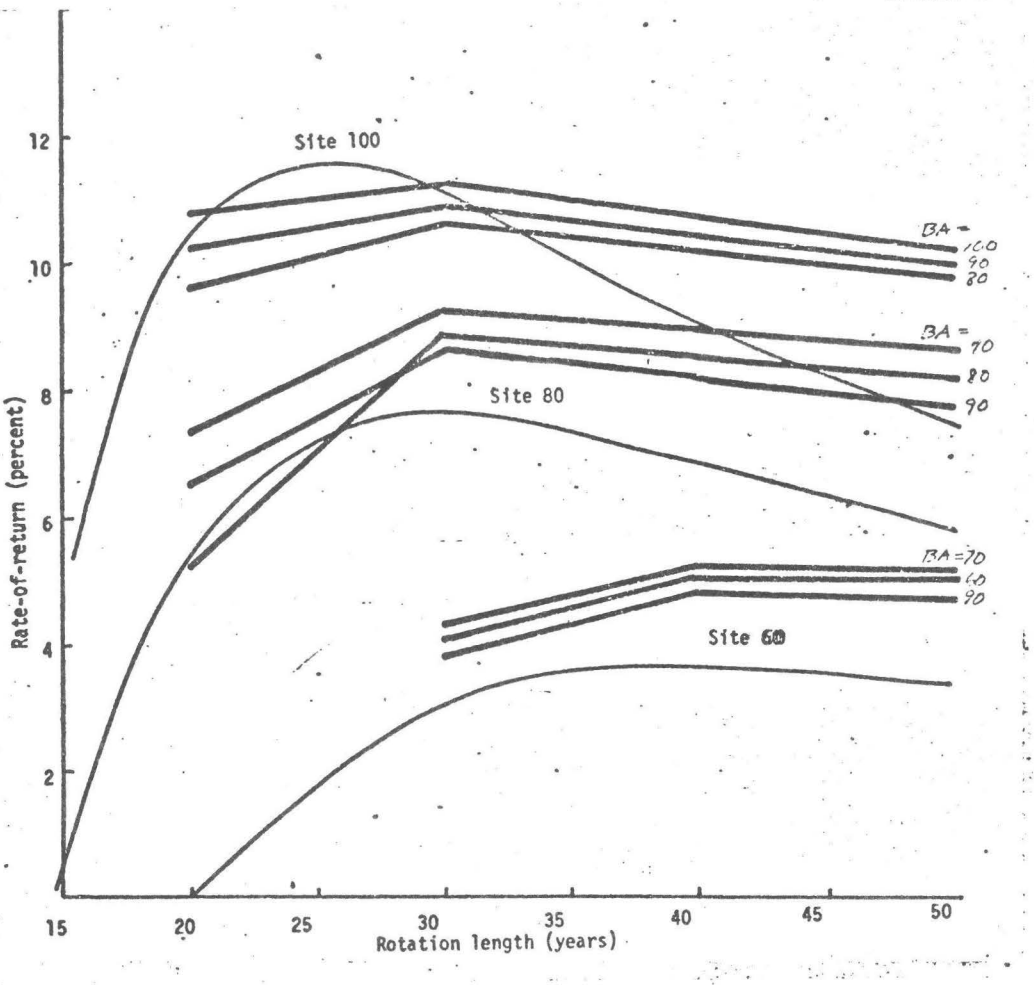


Figure 10.19--Rates-of-return from management level VI--thinned plantations--on cutover land by rotation length, reserve basal area level, and site index.



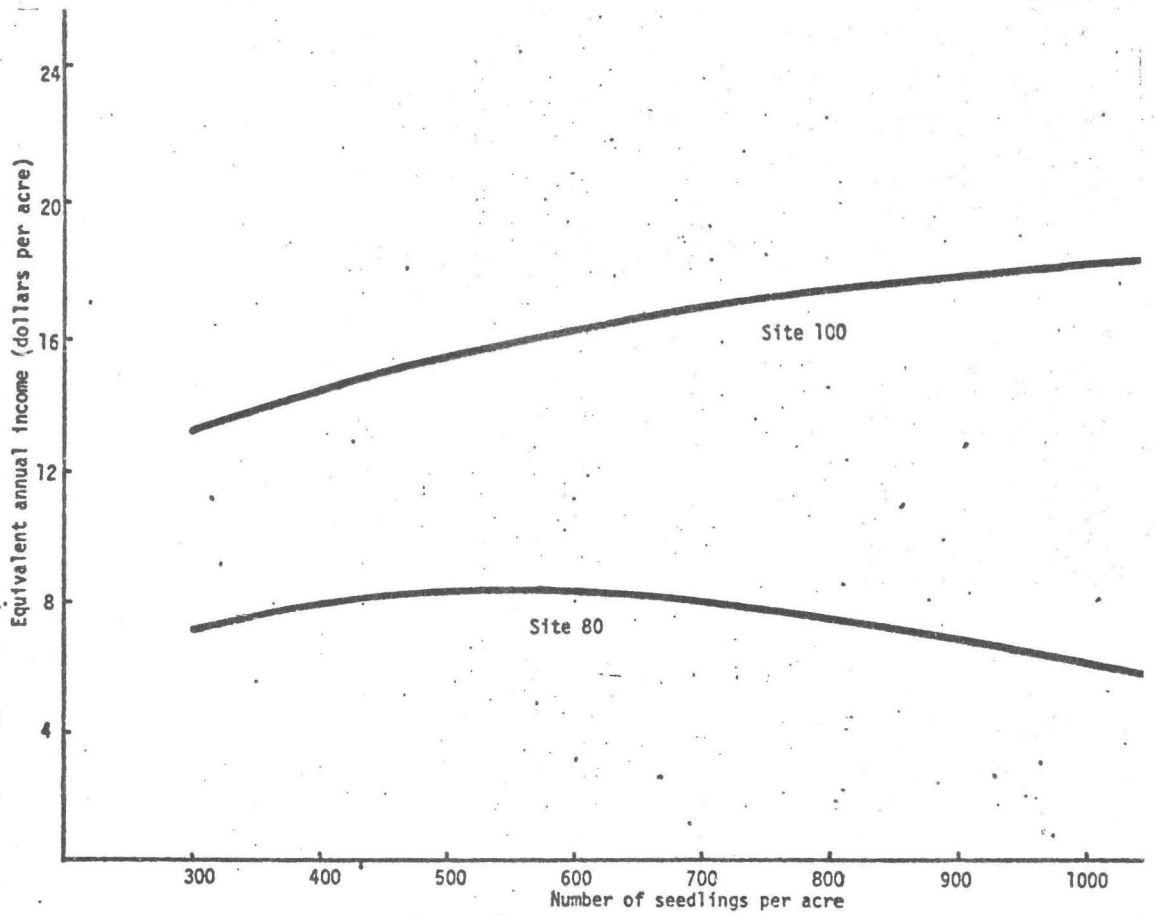
The advantage of thinning appears greatest on site 80 land. There thinnings tend to concentrate the growth on a reduced number of trees. They then grow into the sawtimber size classes at a relatively early age--30 years or so. This greatly improves unit values, and at age 40 the annual income is about twice that from unthinned stands. The best stand density is again about 80 square feet basal area--the same as the best basal area level of natural stands.

On site 100 land, thinning does not appear to have as much advantage as on site 60. At high reserve basal areas the annual returns from thinned plantations exceed that from planted stands. The reason is that even without thinning the trees become sawtimber size. The advantage of larger diameter is substantial but not as relatively great as the increase from smaller diameters found in thinned site 80 plantations.

The effect of additional trees planted is not as large as with unthinned plantations. The extra trees are removed in early thinnings and sold at generally low unit values. For site 80 plantations the best density is about 500 trees, as shown in figure 10.20. This confirms the conventional wisdom. But on site 100 land the returns increase moderately with increased seedling numbers. But the effect is not sufficiently large to offset the potential gains from higher lumber prices and interest rates.

As for the previous management levels the incomes from thinned pine plantations were simulated for old fields and for

Figure 10.20--Annual incomes per acre from management level VI--thinned plantations--on cutover land--by number of seedlings per acre and site index.



converted hardwood lands. The results parallel the results for the cutover land and differ by only the difference in amortized values of the initial regeneration treatments (figure 10.21).

The cutover land management regimes selected for study are summarized in table 10.8 and shown in detail in Appendix II. All regimes assumed 500 trees planted per acre.

Management level VII--Genetically improved plantations

One of the major research accomplishments in the last decade is the introduction of seedlings from improved genetic source material. This is the culmination of several decades of effort in selecting superior trees, grafting, crossing, testing the progeny. In several southern states seedlings of improved genetic material are being sold by state nurseries. Forest industries are already using a high proportion of genetically improved seed sources (Guttenberg, 1969).

There are several levels of genetic improvement. The type most commonly available is the result of open pollination among selected grafted material in seed orchards. The available information is scanty, but recent studies show that a genetic gain of 20% in volume can be expected from such sources. This was the basis for one of the limited economic analysis of the advantages of genetic gain (Row, 1968).

Using this assumption the model simulated the increased economic returns from improved genetic stock. The increased growth effect was approximated by simulating the effect of a wide range of site indexes on average per acre growth, fitting

Figure 10.21--Comparisons of incomes from management level VI--thinned plantations--on old field land and converted hardwood land, by rotation length and site index.

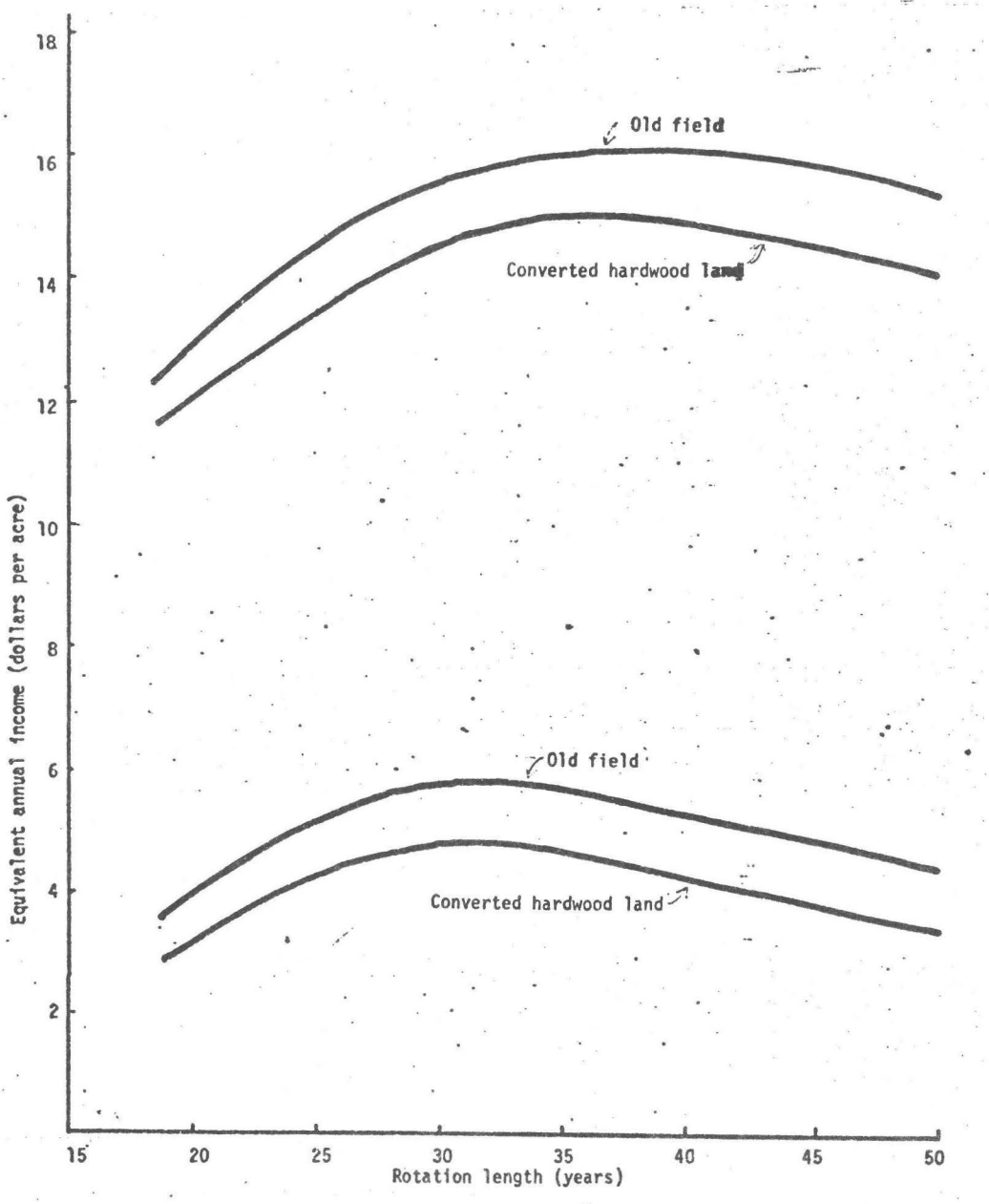


Table 10.8--Data for alternatives in management level VI selected for further simulation.

Criterion and item	Cutover Site 60	Cutover Site 80	Cutover Site 100	Old field Site 60	Old field Site 80	Old field Site 100	Hardwoods Site 60	Hardwoods Site 80	Hardwoods Site 100
Annual income criterion									
Annual income ($s)	*****	5.51	11.93	*****	5.84	16.03	99.99	4.89	14.87
Rate of return (%)	*****	8.8	10.1	*****	8.1	9.9	*****	6.8	8.8
Harvest age (yrs)	*****	40.	40.	*****	30.	40.	*****	30.	40.
Harvest diameter (in)	*****	15.5	18.9	*****	11.4	16.6	*****	11.4	16.6
Avg pine yield (cuft)	*****	102.7	168.7	*****	122.0	204.9	*****	122.0	204.9
Avg pine grow stock (cuft)	*****	1267.	2096.	*****	1092.	2478.	*****	1092.	2478.
Compromise criterion									
Annual income ($s)	*****	5.12	10.76	*****	*****	*****	*****	*****	*****
Rate of return (%)	*****	8.8	9.9	*****	*****	*****	*****	*****	*****
Harvest age (yrs)	*****	40.	40.	*****	*****	*****	*****	*****	*****
Harvest diameter (in)	*****	16.5	19.9	*****	*****	*****	*****	*****	*****
Avg pine yield (cuft)	*****	98.9	163.3	*****	*****	*****	*****	*****	*****
Avg pine grow stock (cuft)	*****	1152.	1940.	*****	*****	*****	*****	*****	*****
Rate-of-return criterion									
Annual income ($s)	*****	5.74	10.79	*****	5.84	15.60	*****	4.89	14.56
Rate of return (%)	*****	9.6	10.7	*****	8.1	10.4	*****	6.8	9.1
Harvest age (yrs)	*****	30.	30.	*****	30.	30.	*****	30.	30.
Harvest diameter (in)	*****	12.0	14.6	*****	11.4	13.5	*****	11.4	13.5
Avg pine yield (cuft)	*****	101.9	165.5	*****	122.0	216.1	*****	122.0	216.1
Avg pine grow stock (cuft)	*****	933.	1544.	*****	1092.	1941.	*****	1092.	1941.

a function, and solving for the site index corresponding to a 20 percent volume growth gain for sites 60, 80, and 100. The sites that would produce that gain are 64, 86, and 108 respectively.

The additional cost of the improved seedlings are only a few cents per thousand. At this cost the effect on per acre planting costs would be negligible, and thus no other change was made in the input assumptions other than the productivity gain.

The results are shown in figures 10.22 and 10.23. The annual incomes are as much as 60 percent higher than with unimproved seed. As expected, the gain is most noticeable with site 100 land, though the gain for site 80 land is substantial--about 30 percent. Contrary to expectations of some in the industry (Guttenberg, 1969), the effect of genetically improved stock is not to reduce the rotation age. It remains the same--30 years (table 10.9).

Since it is clear that genetically improved stock has a clear advantage over unimproved material, it is not necessary to introduce this in Chapter 11. Owners with access to the improved seedlings will, of course, use them.

Effect of economic factors

The previous sections of this chapter presented the effects of levels of management, probability of regeneration, number of seedlings planted, and site index on annual incomes per acre, rates-of-return, rotation age, and thinning policy.

Figure 10.22--Annual incomes from management level VII--genetically improved seedlings in unthinned plantations on cutover land, by rotation age and site index. For comparison, incomes from unimproved stock are shown by dotted lines.

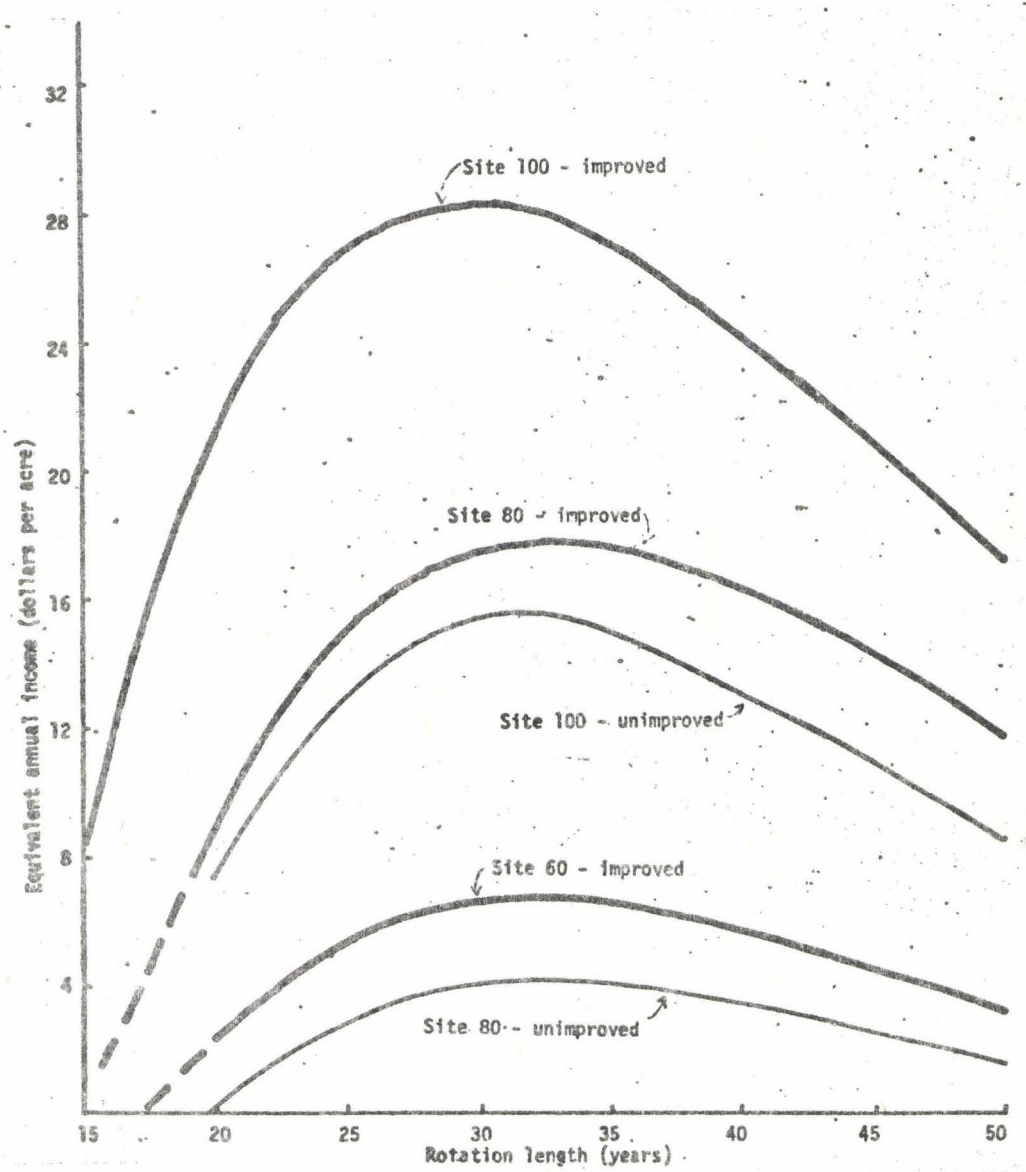


Figure 10.23--Rates-of-return from management level VII--genetically improved seedlings in unthinned plantations--on cutover land, by rotation age and site index.

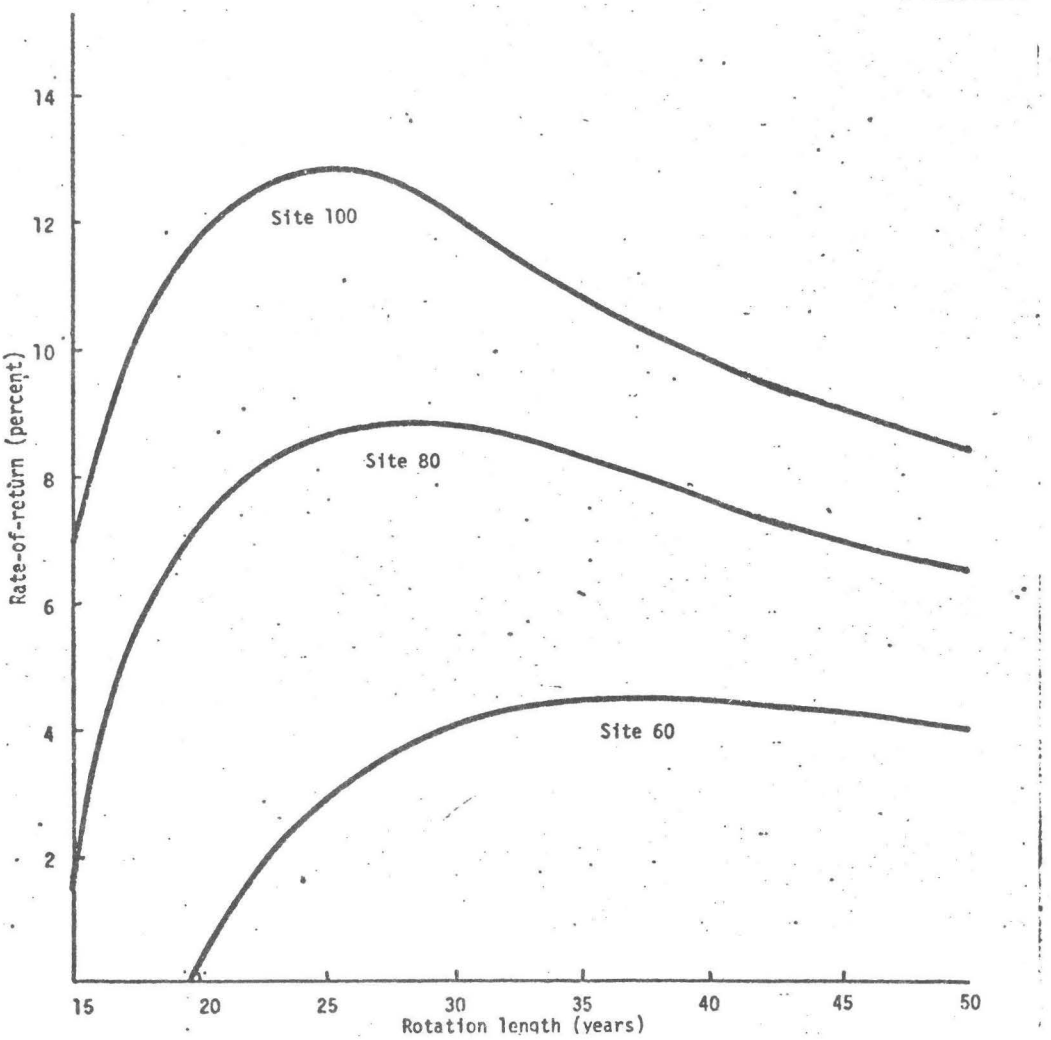


Table 10.9--Data for alternatives in management level VII selected for further simulation.

Criterion and item		Cutover Site 60	Cutover Site 80	Cutover Site 100
Annual income criterion				
Annual income	($s)	*****	4.12	15.68
Rate of return	(%)	*****	7.4	10.8
Harvest age	(yrs)	*****	35.	30.
Harvest diameter	(in)	*****	9.0	10.1
Avg pine yield	(cuft)	*****	119.6	211.6
Avg pine grow stock	(cuft)	*****	1541.	2273.
Compromise criterion				
Annual income	($s)	*****	3.47	14.84
Rate of return	(%)	*****	6.9	9.9
Harvest age	(yrs)	*****	40.	35.
Harvest diameter	(in)	*****	9.3	10.6
Avg pine yield	(cuft)	*****	120.2	216.3
Avg pine grow stock	(cuft)	*****	1910.	2942.
Rate-of-return criterion				
Annual income	($s)	*****	3.94	14.75
Rate of return	(%)	*****	7.7	11.6
Harvest age	(yrs)	*****	30.	25.
Harvest diameter	(in)	*****	8.7	9.5
Avg pine yield	(cuft)	*****	115.0	197.0
Avg pine grow stock	(cuft)	*****	1161.	1600.

The remaining section of this chapter discusses the effect of a number of exogenous economic factors on the selection of management level, rotation age, and reserve basal area policies. Cost levels and trends, price levels and trends, and size of tract will be considered in order.

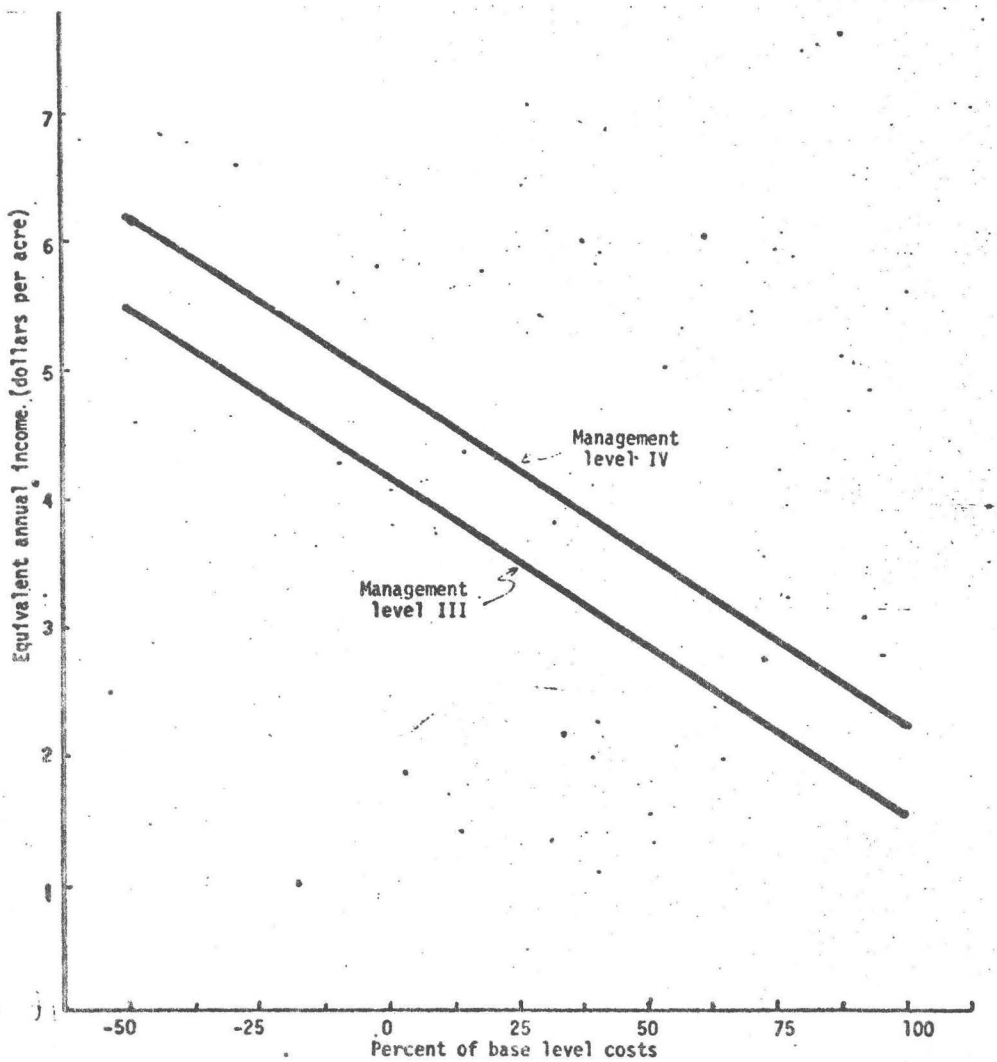
Cost levels and trends

The discounting procedure that estimates the equivalent annual income per acre in effect amortized the costs of regeneration over the entire rotation period. In addition there are maintenance or operating type costs that occur annually or periodically. Varying levels of these costs would naturally be expected to have considerable influence over the annual incomes received. The effect of a range of cost levels from 50 percent to double the levels given in Chapter 7 are shown in figure 10.24 for 40 year rotations. The effect is linear, with a doubling of costs causing about a 60 percent drop in annual income.

Increased cost levels have a slight effect on the best rotation age since higher costs can be amortized over longer periods. Simulations using a 50 percent increase in general cost structure lengthened the best rotation length of both management levels III and VI about five years.

The effect of an increasing cost trend is also to decrease the income per acre but not at the same rate. The heavy costs at the beginning of the rotation are not affected. The cost trends assumed in this study are linear, rather than exponential.

Figure 10.24--Effects of level of cost on equivalent annual income from management level III and VI for 40 year rotations.



Thus a 2 percent per year increase is equivalent to an 80 percent increase in the costs of regeneration after a 40 year rotation. Costs trends have only a minor effect on best rotation age.

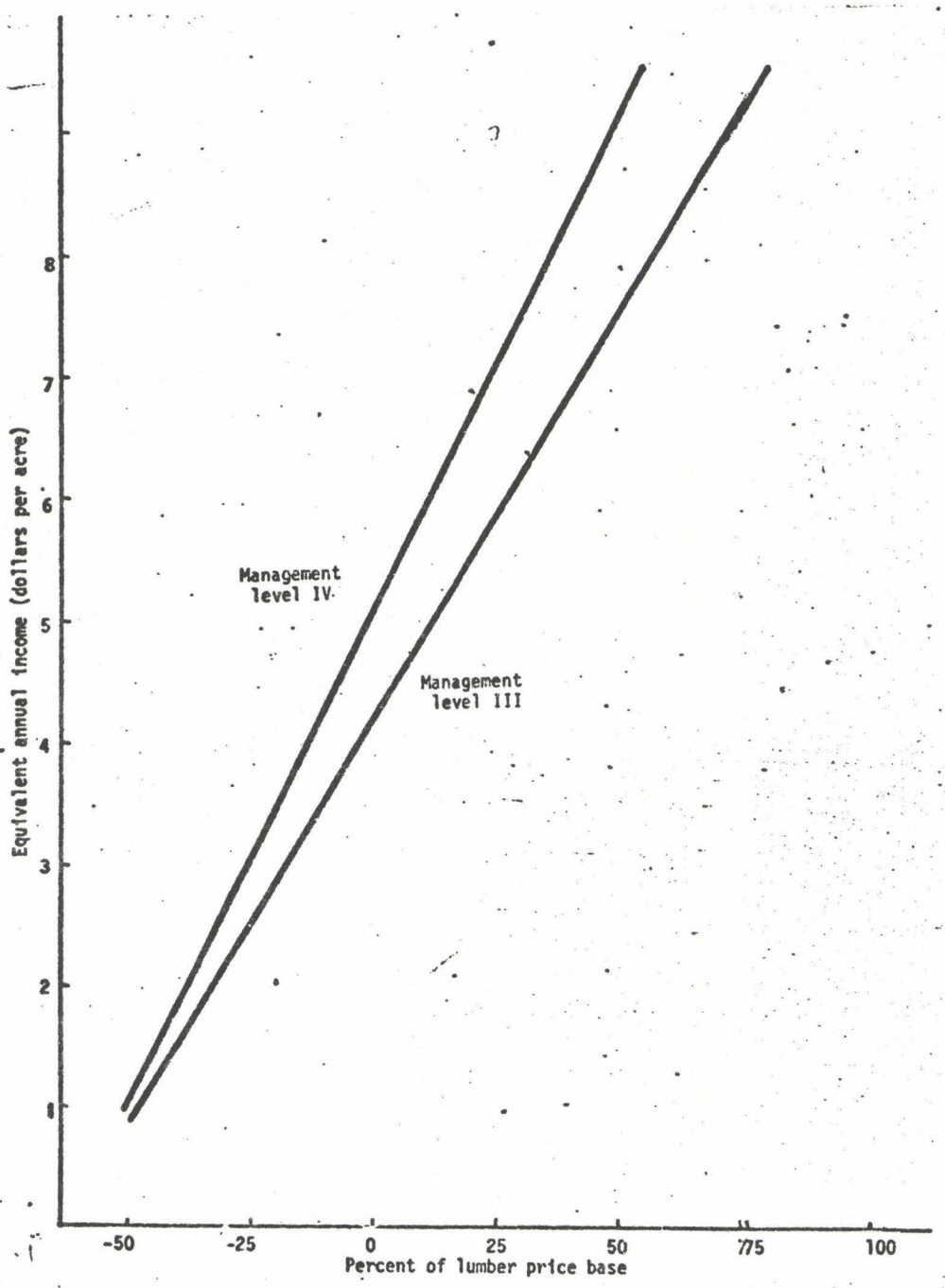
Timber price levels

An increase in the level of timber prices has a very sharp and more than proportionate effect on income per acre. The incomes per acre generated by increased levels of prices are shown in figure 10.25. The relationships are linear but depend partially on management level. An increase of 100 percent in prices causes a 125 to 175 percent increase in income per acre. An increase in the general price of timber of 50 percent causes no appreciable change in best rotation age.

If the increase in timber prices follows a linear trend, the effect is much the same as for a level price increase. The effect is smaller for thinned stands, given the same overall increase by the end of the first rotation. An increasing timber price trend of only 1 percent a year, however, lengthens the most desirable rotation age about 10 years. The timber at the end of longer rotations is proportionately more valuable than with shorter rotations, and it pays for the forest owner to keep the timber for a longer period. This effect may be important, since the historical trend in timber prices since 1800 has been irregularly upward at about 1.8 percent a year.

Lumber price levels

Figure 10.25--Effects of levels of timber prices on equivalent annual income per acre for management levels III and VI, for 40-year rotations.



Through its indirect effect on general timber price levels (developed in Chapter 6), lumber prices have an important effect on incomes per acre expected from timber growing regimes. The effect was measured by simulating 2 series of rotations (30 and 40 years) of a thinned plantation--management level VI. The effect of a given percentage price increase is almost as dramatic as the effect of a general timber price rise of similar magnitude. The rate of rise is shown in figure 10.26.

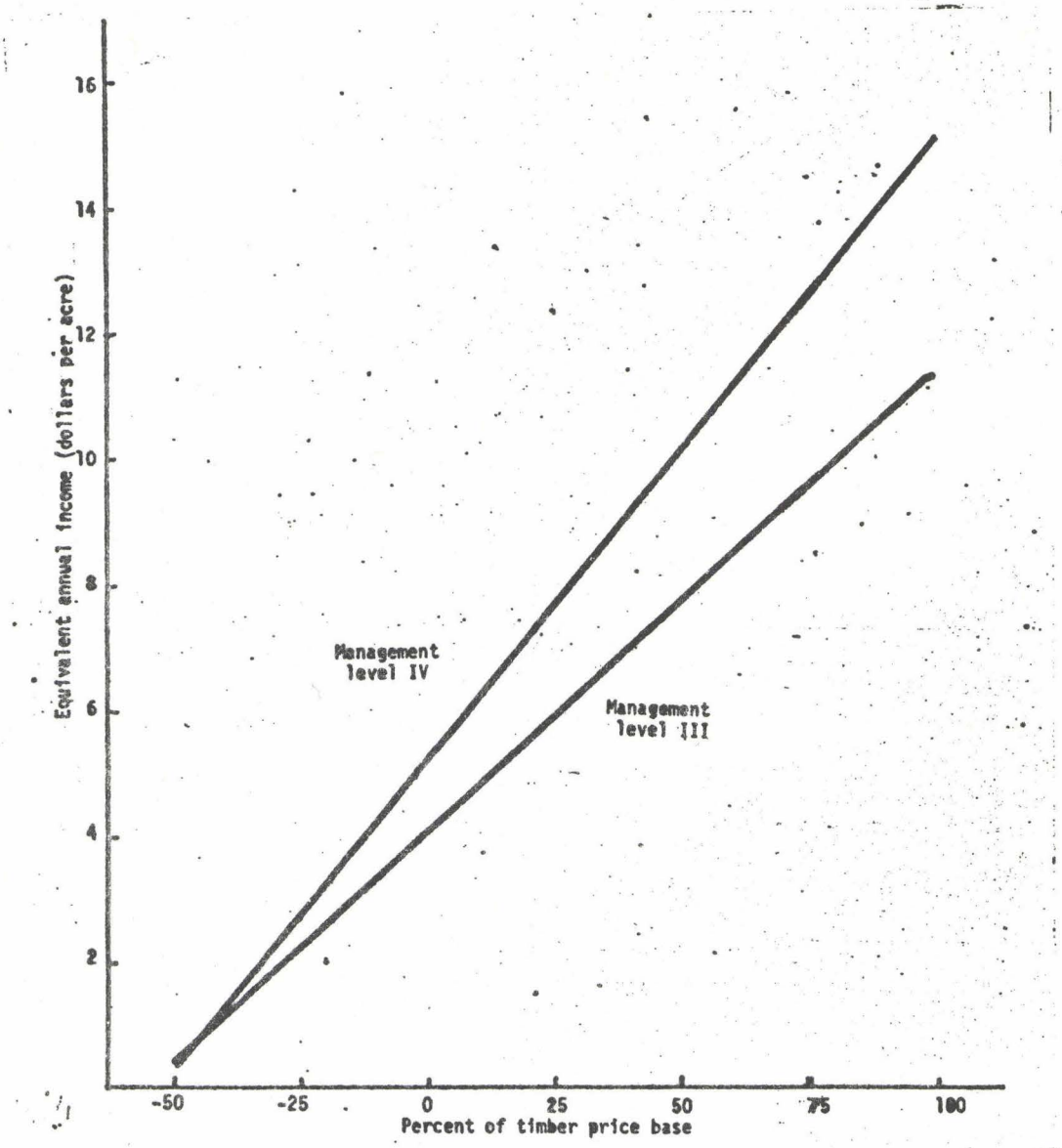
The effect is more significant, as expected, with longer rotations rather than shorter, as the price rise line for a 40-year rotation is steeper than for a 30-year rotation. Thus simulations of the rotation ages indicates that a lumber price rise will shift the length of the best rotation about 5-10 years.

The effect of lumber price trend is nearly the same as an increase in lumber price level. Lumber prices influence incomes primarily at time of harvest cut, the only sale in which the timber is usually sawtimber size in the rotations considered. Thus for an equivalent rise by the end of the rotations, it makes little difference whether the increase comes all at once at the beginning of a rotation or at the end.

Effect of tract size

In Chapters 6 and 7 the regression analyses suggested that for both costs and prices, a fixed cost per acre per treatment or sale was significant. The fixed cost of treatments seemed largely determined by the extent of equipment involved in the

Figure 10.26--Effects of lumber price level on equivalent annual income per acre for management level III and VI, for 40-year rotations.



particular technique used. Hand planting has a relatively low fixed cost, while helicopter operations had very high fixed cost per contract. The effect of these fixed costs is to make treatment costs per acre high for small tracts relative to large ones, since the fixed cost can be spread over fewer acres.

Simulations were run on several of the major management levels to determine the aggregate effect of size of tract on the costs and revenues per acre. The results for management levels I and level III and VI are shown in figures 10.27 and 10. 28for sizes of tracts that increase exponentially from 10 acres to 2560. The effect on site 60 land is much more pronounced than on site 100 land reducing the net income to zero on relatively large tracts. Though annual incomes are not reduced to zero within the range of sizes used, the penalties for small tract size are significant. The effect for the management level VI is stronger than for III because site preparation, planting and spraying operations all have significant fixed costs. The effect on incomes from hardwood forest land that must be cleared to plant pine is even more pronounced, and even the best sites must be in tracts larger than 50 acres for conversion to be economically feasible.

Among the moves that owners of small tracts may take to reduce the effect of tract size is to combine their holdings with other forest lands so as to have combined treatment and sales operations and thus reduce the fixed costs. Several strong trends in the South have their basic rationale in this problem.

Figure 10.27--Effect of tract size on equivalent annual income per acre from management level I--unmanaged stands, by site index class.

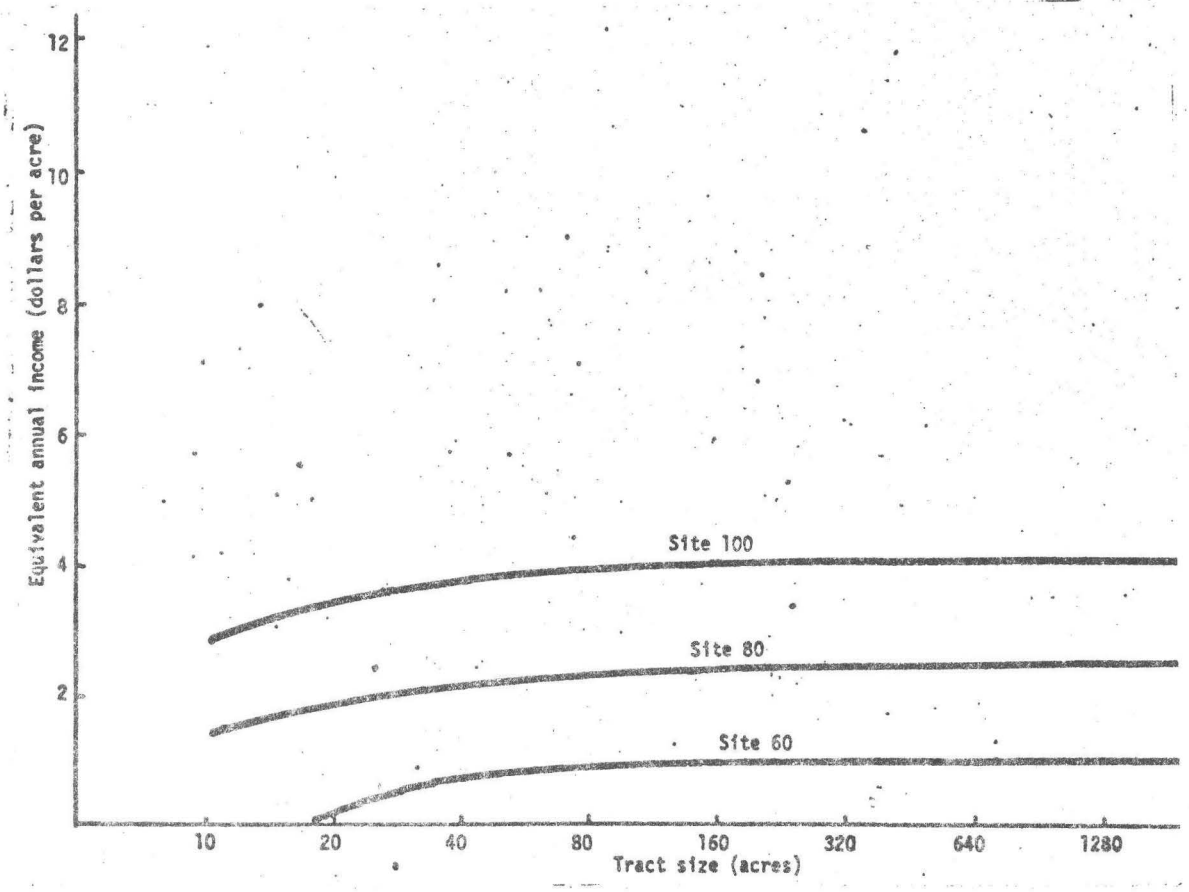
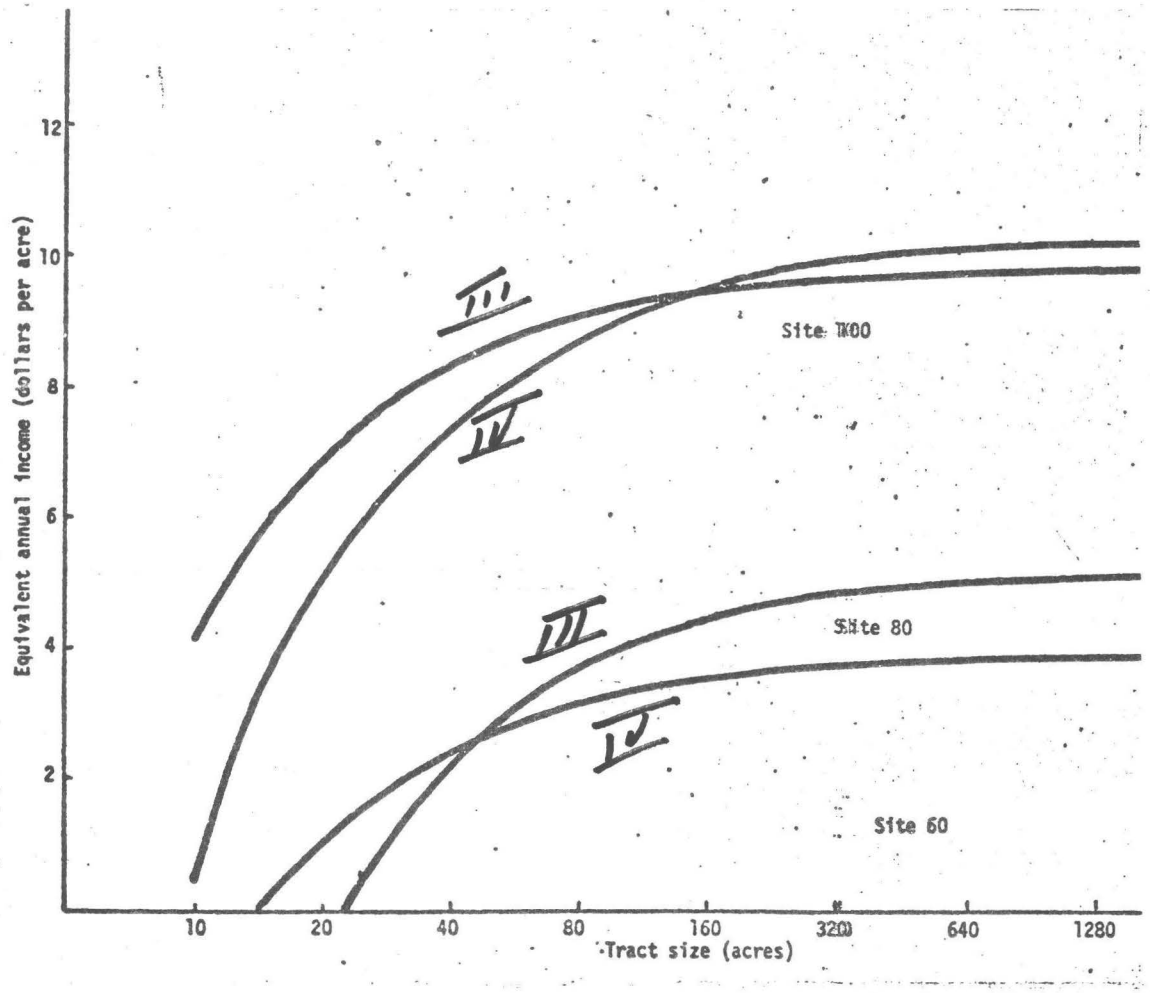


Figure 10.28--Effects of tract size on equivalent annual income per acre for management levels III and VI, by site index class, for 40-year rotations.



Among them are:

1. Long-term leasing of small and medium sized tracts to forest product industry firms, who absorb the small acreage in their holdings for all practical purposes and manage the land as they do their own (Siegel, 1969). Leases often run to 99 years, with payment to the owner on a schedule and at prices negotiated at the time of lease. Payments are often linked by an escalator clause to forest product prices.

2. Management of small and medium sized holdings by firms of consulting foresters and land managers, who are able to schedule and pool operations of a number of properties so that they reduce the impact of separate contracting for services (Pleasonton, 1966). Sales may be handled jointly or may not.

3. Associations of landowners. A number of forms of landowner associations have been formed in the South in recent years, some of which have been successful, and others not (Guttenberg, 1973). These associations often seek only to combine to provide treatments at lower cost to the members, or to arrange for sales on a joint basis. The sponsorship of these associations has most often been public agencies.

Summary

This chapter presents the results of simulating alternative management regimes on a deterministic basis. For each of the several management levels at least three regimes were chosen for each combination of land condition class and site index class

studies. Some combinations did not result in minimally acceptable management schedules. In effect, the procedure used screen the numerous alternative regimes for those that are efficient and likely to be chosen by landowners of various ownership sizes and tax situations.

Chapter 11

SELECTING AMONG ALTERNATIVE REGIMES ACCORDING TO INCOME AND RISK

The previous chapter identified for each level of management several management regimes that appeared efficient in producing income. The deterministic procedure used ignored effects of risk and uncertainty (other than regeneration) on expected returns. This present chapter demonstrates the use of a mean-variance or Markowitz approach to selecting among these efficient alternatives on the basis of two criteria simultaneously--in this case average expected equivalent annual income and the standard error of annual income.

Impacts of types of variation

To understand the total impact of risk on financial returns it is necessary to describe the effects of each major type of risk or variation separately. Only selected management regimes will be used to illustrate these losses. The three main sources of variance in expected returns arise from the following sources:

Variation in physical yields

Wide variation in physical yields occur in "normal stands"--well stocked stands in which no major losses have occurred from fire, storm, disease, and insects. As discussed in Chapter

5, these arise from a technical inability to measure accurately the factors that affect (a) site productivity, which determines height growth and influences diameter growth, (b) stocking and other factors that determine diameter growth, and (c) the degree of success in regeneration--whether the establishment of natural seedlings or survival of planted nursery stock.

The degree of variation estimated from available evidence in Chapter 5 was as follows:

1. Site index can be established from the height growth of the previous stand or from soil measurements within a stand deviation of ±10 percent for a 10 acre tract. The accuracy of repeated measurements declines in proportion to the cube root of the area, since successive measurements on adjoining areas tend to be highly correlated. This suggests that sampling for site index on a tract of 160 acres, for example, may be quite accurate--within ± 1.8 feet. This corresponds to a range of variation in volume growth of ± 6 percent for site 80 land from this source.

2. From studies of growth variation on small plots with the same apparent site productivity or height growth, an additional variation of ± 30 percent on a 10 acre basis can be expected. Since the causes of this variation are extremely diverse it was thought that the factors are probably not highly correlated from one area in a tract to an adjacent one. Variation within a tract is expected to decline in proportion to the square root of area. Thus the error from this source on yields for a 160 acre tract would be expected to be about ± 7.5 percent.

3. Variation encountered from degrees of success in stand establishmentare more complex. They were discussed in detail in Chapter 5 and the effects on volume yield and on annual income in connection with management level III were presented in Chapter 10. In natural stands, where the degree of risk from both understocking and overstocking are most severe, the extremes of stocking can cause complete loss of income within the length of management periods considered in the study. For this type of variation, however, there are management actions that can reduce the impact, but at a cost. If regeneration is insufficient the land can be reprepared. If the regeneration is so abundant that it causes stagnation, the stand can be precommercially thinned to reduce stocking. If the conditions occur in the stochastic simulation process, these treatments are prescribed in management levels III and IV.

Effect of growth process variations. Stochastic simulations showed the combined effect of growth variation on annual income and rate-of-return. A set of 30 trials assumed management level IV, site 80 land, 40 year rotations, and thinning to 80 sq. ft. basal area. The same conditions prevailed as in the corresponding level of management in Chapter 10. The resulting equivalent annual income and rates of return are as follows:

	Annual Income		Rate of return	
	Mean	Std. dev.	Mean	Std. dev.
Without variation	3.75	-	7.89	-
With growth variation	3.37	±1.66	7.80	±1.15

With t-tests of 1.45 and .43 respectively, the difference in mean annual income is just marginally at 10 percent probability level. The difference in rate-of-return is not significant.

The slight loss in expected annual income appears to come from a relatively few cases that had regeneration losses or required precommercial thinning.

The distribution of both equivalent annual incomes and rates of return are not normally distributed. The percent of trials in $1 intervals of annual income are:

Annual income	Percent
$0. - .99	7
1.00 - 1.99	0
2.00 - 2.99	10
3.00 - 3.99	13
4.00 - 4.99	42
5.00 - 5.99	23
6.00 - 6.99	3

Nearly all of the trials that resulted in annual incomes in the $3.00 to $4.00 range were overstocked and had to be precommercial thinned. All of the trials yielding less than $2.00 annual income had a regeneration failure in the first rotation.

Of importance to timber supply is the effect of variation in biological growth processes in average yields per acre. Management regime IV would produce 130.7 cubic feet per acre per year if the stocking of seedlings were as heavy as indicated by the Schumacher-Coile normal stocking. Assuming median regeneration

3. Variation encountered from degrees of success in stand establishmentare more complex. They were discussed in detail in Chapter 5 and the effects on volume yield and on annual income in connection with management level III were presented in Chapter 10. In natural stands, where the degree of risk from both understocking and overstocking are most severe, the extremes of stocking can cause complete loss of income within the length of management periods considered in the study. For this type of variation, however, there are management actions that can reduce the impact, but at a cost. If regeneration is insufficient the land can be reprepared. If the regeneration is so abundant that it causes stagnation, the stand can be precommercially thinned to reduce stocking. If the conditions occur in the stochastic simulation process, these treatments are prescribed in management levels III and IV.

Effect of growth process variations. Stochastic simulations showed the combined effect of growth variation on annual income and rate-of-return. A set of 30 trials assumed management level IV, site 80 land, 40 year rotations, and thinning to 80 sq. ft. basal area. The same conditions prevailed as in the corresponding level of management in Chapter 10. The resulting equivalent annual income and rates of return are as follows:

	Annual Income		Rate of return	
	Mean	Std. dev.	Mean	Std. dev.
Without variation	3.75	-	7.89	-
With growth variation	3.37	±1.66	7.80	±1.15

With t-tests of 1.45 and .43 respectively, the difference in mean annual income is just marginally at 10 percent probability level. The difference in rate-of-return is not significant.

The slight loss in expected annual income appears to come from a relatively few cases that had regeneration losses or required precommercial thinning.

The distribution of both equivalent annual incomes and rates of return are not normally distributed. The percent of trials in $1 intervals of annual income are:

Annual income	Percent
$0. - .99	7
1.00 - 1.99	0
2.00 - 2.99	10
3.00 - 3.99	13
4.00 - 4.99	42
5.00 - 5.99	23
6.00 - 6.99	3

Nearly all of the trials that resulted in annual incomes in the $3.00 to $4.00 range were overstocked and had to be precommercial thinned. All of the trials yielding less than $2.00 annual income had a regeneration failure in the first rotation.

Of importance to timber supply is the effect of variation in biological growth processes in average yields per acre. Management regime IV would produce 130.7 cubic feet per acre per year if the stocking of seedlings were as heavy as indicated by the Schumacher-Coile normal stocking. Assuming median regeneration

success, yields drop to 99.1 cubic feet per acre per year. In the simulation of variations in all biological processes, the average yield is 97.8 cubic feet per acre per year with a standard error of 14.8. The drop of 25 percent from the output expected from yield study is of course highly significant.

Variation in costs and prices

Costs of management practices show extremely wide variation, particularly for small tracts. The cost variation assumptions used in this study are given in Chapter 7. Prices of timber also show wide variation, primarily because the major influence is the highly volatile lumber price history. This price variation is discussed in Chapter 6.

An unknown aspect is the degree to which cost and price variations are correlated, and if they are, the degree that they affect each other. This would occur if areas with either high or low prices have consistently either high or low costs. A positive correlation between costs and prices would tend to reduce the variation in financial returns, a negative correlation would increase the amount of variation. Detailed consideration of such possible correlations is beyond the scope of this study. But if independent variation of cost and product values is assumed the effects tend to average out throughout a rotation. Put another way, whether a owner will get a good or bad deal on successive transactions is assumed in this study to be completely random.

Effect of cost and price variation. Stochastic trials assuming only variations in costs and prices showed the effects on annual income and rates-of-return that can be expected. In a test similar to that for growth process variation on level of management IV, a set of 30 trials was made with the cost and price variation (but no trend in costs). The results were as follows:

	Annual income		Rate of return	
	Mean	Std. dev.	Mean	Std. dev.
Without variation	3.81	-	7.89	-
With cost and price variation	3.68	1.13	7.59	.53

The difference between the mean annual income per acre with and without variation is not significant ($t = .63$), but the difference caused by cost and price variation in rate-of-return is highly significant ($t = 3.05$). Since the cost and price variation is normally distributed and the discounting at a specified rate of interest tends only to make the range of variation smaller, cost and price variation should not be expected to bias annual income estimates.

In rate of return computations, however, large positive variations in prices for the timber at the end of the rotation would cause rates-of-return to increase, but not as much as similar negative variations cause a decreases in rates-of-return. Thus wide variation in costs and prices produces a negative bias in rate-of-return estimates, which was confirmed by the simulation. This is perhaps an additional argument against using rate-of-return as a criterion for investment decisions.

Variation caused by natural losses

The third general cause of variation are losses and other changes in the stand of timber due to fire, storm, insects, and disease. These losses were discussed in Chapter 8. Variation caused by these natural agents differs from that caused by growth process and by costs and product prices in several respects: (a) all of the variation is loss, and therefore has a negative bias on yields and returns, (c) losses do not correspond even approximately to a normal distribution. There is a relatively high rate of total loss for portions of rotations. These losses are offset to some extent by salvage values.

In TIMSIM two types of natural agent loss are recognized. First is loss in forest acreage worth further management without regeneration. The program specifies that a loss that effectively kills 60 percent or more of the basal area would destroy the value of the stand for further management. Furthermore, if 50 percent or more of a merchantable stand is destroyed, a prudent owner would salvage the timber and regenerate the entire tract.

The second type of loss is partial loss of growing stock basal area with subsequent loss of growth and value. If such a loss occurs, the quality of the stand accumulated up to that point is lost. This type of loss is more common but not as severe as a heavy destruction. Since the stand is in effect thinned, subsequent growth is proportionally faster than if the stand were not touched. If the loss in basal area was less than 3 square feet, the effect was considered negligible and not computed.

Effect of losses on returns. A set of 30 trials using the same management regime as for growth variation and cost and price variation (level IV) permitted evaluation of the typical effect of combined fire, storm, and insect losses on the stand. Again the site index was 80, and the stand was thinned to 80 square feet basal area. The resulting impacts on equivalent annual income per acre and rate-of-return are as follows:

	Annual income		Rate-of-return	
	Mean	Std. dev.	Mean	Std. dev.
Without variation	3.81	--	7.89	--
With fire, storm, and beetle losses	3.46	1.04	7.84	.68

With t-tests of 1.84 and .40 these differences are highly significant for annual income and not significant for rate-of-return. The distribution of annual incomes is highly skewed, with the losses detracting, to greater or lesser extent from normal yields. In 2 trials total losses in first rotation cut incomes to 30 percent or less of "normal". The distribution is as follows:

Annual income	Percent of trials
0 - $ .99	7
1.00 - 1.99	0
2.00 - 2.99	10
3.00 - 3.99	27
4.00 - 4.99	56

To determine whether the loss rates simulated by the program were reasonable, they were separated into components. Gross undiscounted revenues per acre per year for the management regime

are as follows:

	Revenue per acre per year	Percent of no loss
Without variation	$17.95	100.0
Losses from destruction of area	1.58	8.8
Patrial losses of basal area	1.66	9.2
Salvage values	(-.74)	(-4.1)
Net losses of gross revenue	2.49	13.9

Since the impact of these losses is felt in harvest cuts and in loss of quality, the loss in volume is only about 2/3 the loss in gross values. If this is considered the rate of loss in the simulated program agrees quite closely with the 10.4 percent average losses in annual growth due to mortality experienced on all southern pine forest types. Though the comparison is not exact, it indicates that the rate of losses simulated by the model are reasonable.

The foregoing loss rates mentioned are in gross revenues per acre per year. Translated into terms of equivalent net annual income per acre the percentage loss is not as great--9.1 percent. The primary reason is that most of the losses occur near the time of harvest and are discounted for the entire rotation period.

The characteristics of planted stands make them more susceptible to losses. Young plantations can be easily destroyed by fire. Once established the plantations are somewhat more dense, taller

in proportion to diameter, and are thus more vulnerable to storm and insect losses.

Additional stochastic simulations established the rate of losses in plantations. The first set of trials provided only for losses from fire, storm, and insect losses. Using management level VI--thinned plantations --similar site index (80) and basal area guide for thinning (70 square feet), the results were as follows:

	Annual income		Rate of return	
	Mean	Std.dev.	Mean	Std. dev.
Without losses	3.99		7.37	
With fire, insect, and insect losses	3.12	±2.27	6.79	±1.30

The t-tests--2.11 and 2.44--are both significant.

The results indicate that impacts of these causal agents are relatively larger in plantations than they are with similar management levels of natural stands.

In addition, planted stands are subject to fusiform rust discussed in Chapter 7. In many areas of the South the rates from infection of seedlings ranges up to 70 percent or higher. The impact derives from very high mortality of infected trees each growth period. In TIMSIM, it was assumed that the first thinnings would remove the cronartium infected trees first, taking only sound trees after the infected trees had been eliminated. It was further assumed that unless there was 200 healthy trees left in the stand, the stand would be destroyed and the site

reprepared and replanted.

Special trial runs simulated the rate of fusiform rust infection using two factors. The first is a factor gauged to the prevalence of fusiform rust in the vicinity of the plantation. The second is a random generated probability of infection based on surveys of plantations throughout the South and described in Chapter 8. The final probability is the geometric mean between the two. With the regional factor set at .5 and .1, the probability of infection is as follows:

Percent infected	Proportion of trials	
	Factor = .5	Factor = .1
.09 - .09	22	87
.10 - .19	23	13
.20 - .29	22	0
.30 - .39	12	0
.40 - .49	10	0
.50 - .59	12	0

Factor level .5 generates extremely heavy infection rates. Forest owners planting in such an area would be advised to plant relatively large number of trees per acre to offset fusiform rust losses. Thus the number of seedlings in initial test was increased from 500 to 650.

Separate test runs of 30 trials each were made for each level of cronartium infection. They assumed the same management regime (level VI) used previously. The results are as follows:

	Annual income		Rate-of-return	
	Mean	Std. dev.	Mean	Std. dev.
Without losses	3.99		7.37	
With cronartium factor = .5	4.10	.12	7.31	.05
With cronartium factor = .1	3.93	.11	7.24	.05

The impact from cronartium at the levels simulated is not significant on annual income. Thinnings apparently remove the infected trees sufficiently early that the harvest are little affected.

Simulations of combined losses

The final set of simulations in the study combined all of the causes of variations in returns developed in the previous chapters. They were made for the most important land condition--recently cutover forest--and spanned the site index classes of 60, 80, and 100, and management levels from I to VI. Again, each type set of simulation was repeated for 30 trials. The sources of variation are summarized in Table 11.1.

Cost and price trends were established from regressions of past agricultural costs and forest product prices. Potential variation in both cost and price trends are also factors that forest owners or managers have to consider in making decisions on particular management regimes for classes of land.

Owners' guiding rates, tract sizes, and tax situations. In addition to the simulation of pretax benefits and costs, the program simulated net realized income from such investments for different owner classes having diverse guiding rates of interest,

Table 11.1--Sources of variation in full stochastic simulation of alternative management regimes.

Source	Average	Distribution	Std. err.
Site index	As specified	Normal	10 percent for 10 acres
Growth factor	1.0	Normal	30 percent for 10 acres
Establishment risk success	.5	Uniform	-
Plantation survival	(Chapter 5)	Normal	12 log units
Cost trend	1.80 percent/year	Normal	.60 percent/year
Pulpwood price trend	.5 percent/year	Normal	.25 percent/year
Sawtimber price trend	1.5 percent/year	Normal	.50 percent/year
Individual prices	(Chapter 6)	Normal	Form: $a * \hat{Y}^b$
Individual costs	(Chapter 7)	Normal	Form: $a * \hat{Y}^b$
Losses from fire, storm, insects and disease	Distributions specified in Chapter 8		

different tract sizes, and tax situations. These are shown in table 11.2.

The first four owner types are similar in all but tract size and were designed to determine the effect of tract size on the expected annual income and the variance of the estimates. These merely confirm the results of tract size in Chapter 10. Owner types 5, 6, and 7 essentially test the effect of various guiding rates and the corporate form. Types 4 to 7, and pre-tax results will be emphasized in this discussion.

An additional owner type--public agencies--can be inferred from the results without consideration of taxes and is referred to as type 8, pretax results. Medium-sized compartments are often used in public forests for multiple-use reasons. Though public agencies do not pay property taxes, they often make corresponding payments. For example, the U.S. Forest Service pays 25 percent of gross receipts to counties in which the land resides for roads and schools.

Variation of simulation results. Results of the trials of simulations using all of the variation options are shown in Table 11.3 for site 80 cutover land. Both mean annual income and variation of annual income or each combination are shown. Figure 11.1 displays the scatter of mean income--standard error combinations for pretax returns or public ownership.

Both means and standard deviations of variation are estimates and both are subject to wide error. The amount of error of both can be determined from the standard error statistic. The confidence limit 67 percent probability for a sample of 30 is about 18 percent

Table 11.2--Owner attributes in the eight situations included to which the stochastic simulations are applied.

Attribute	Owner situation 1	2	3	4	5	6	7	8
Owner type[1/]	I	I	I	I	I	I	C	P
Tract size	10	20	40	80	160	160	320	160
Guiding rate percent	5	5	5	5	5	5	10	5
Tax rate on ordinary income percent	15	15	15	15	30	50	48	-
Tax rate on capital gains	7.5	7.5	7.5	7.5	7.5	7.5	7.5	-

1/ I = Individual, C = Corporate, P = Public

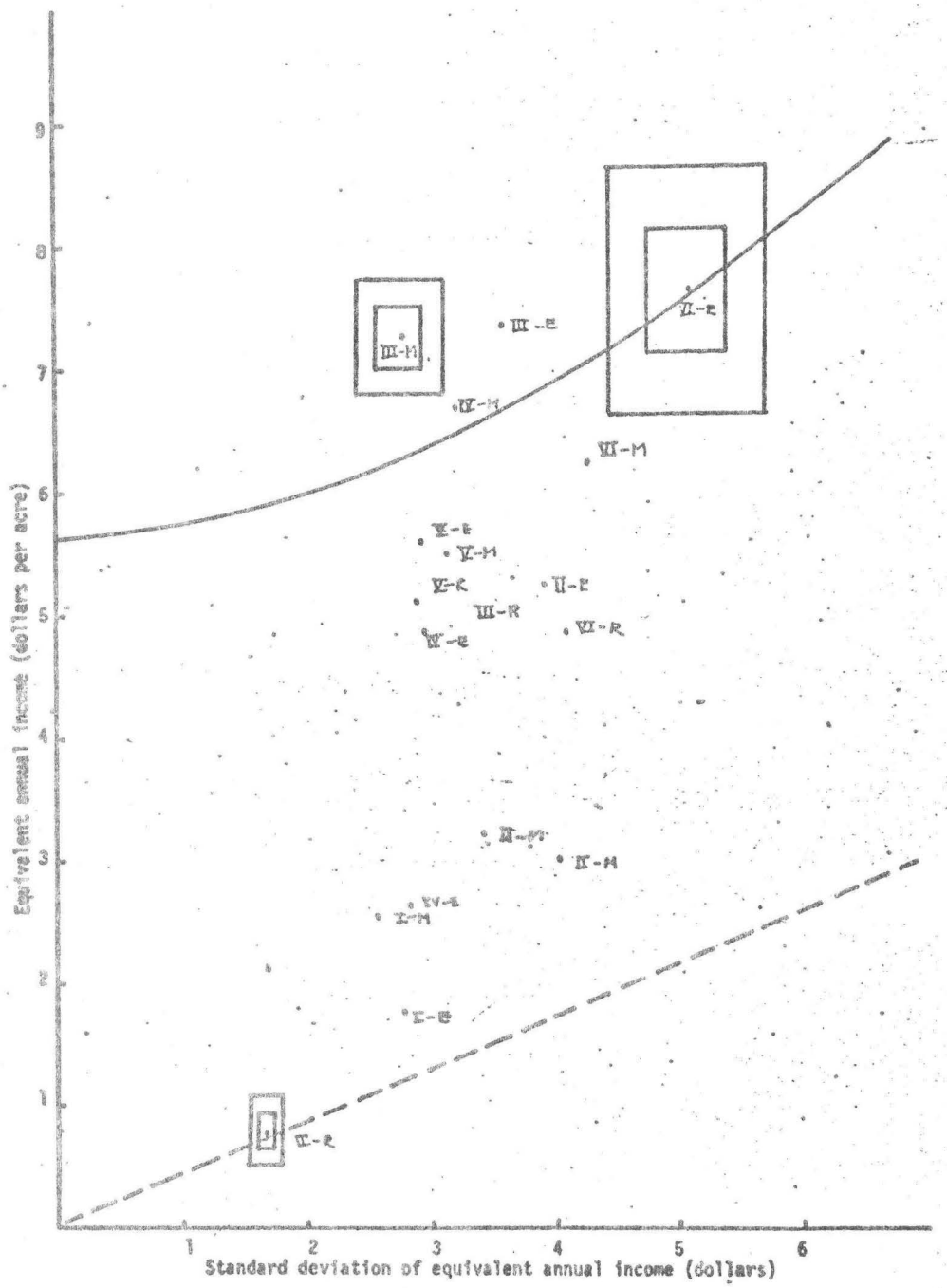
Table 11.3--Mean annual incomes and their standard deviations before taxes and for owner situations 4 to 7 for site 80 cutover land.

Management option 1/	Pretax		Owner 4		Owner 5		Owner 6		Owner 7	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
	(Dollars per acre)									
I-E	1.80	2.78	2.77	4.30	3.87	4.23	4.72	4.18	5.88	5.23
M	7.57	2.53	3.88	3.92	4.86	3.75	5.61	3.63	7.00	4.54
R	.82	1.64	1.06	2.66	2.26	2.48	3.15	2.37	3.94	2.97
II-E	5.27	3.91	6.68	6.50	9.22	6.55	10.61	6.61	13.47	8.26
M	3.04	4.02	2.36	5.86	5.65	5.55	7.55	5.38	9.67	6.72
R	3.38	3.24	2.76	5.06	5.74	4.93	7.41	4.87	9.49	6.09
III-E	7.37	3.54	8.59	5.37	11.76	5.16	13.50	5.10	17.13	6.37
M	7.30	2.73	9.53	5.14	12.86	4.90	14.67	4.85	18.60	6.00
R	5.14	3.29	5.51	5.11	8.56	4.71	10.20	4.53	13.00	5.64
IV-E	4.88	2.98	5.20	4.45	8.45	4.25	10.29	4.23	13.11	5.27
M	6.72	3.15	8.14	4.82	11.82	4.51	13.99	4.33	17.74	5.42
R	2.64	2.83	1.63	4.56	5.41	4.21	7.58	4.05	9.75	5.03
V-E	5.65	2.98	5.07	4.67	8.99	4.57	11.07	4.55	14.18	5.68
M	5.54	3.09	5.52	4.72	9.93	4.67	12.34	4.68	15.79	5.85
R	5.15	2.87	5.25	4.49	9.23	4.33	11.30	4.28	14.49	5.34
VI-E	7.67	5.07	5.14	6.04	9.41	6.12	11.24	6.20	15.06	7.75
M	6.26	4.25	3.04	5.01	7.20	6.01	10.20	5.52	14.30	6.05
R	4.85	4.06	1.75	5.26	6.70	5.13	9.40	5.09	12.19	6.35

1/ E indicates alternative chosen within a management level because they had highest equivalent annual incomes, R because they had highest rate-of-return, and M are compromise alternatives.

The symbols $\bar{x}$ and σ indicate average and standard deviation respectively.

Figure 11.1--Management alternative ranked according to pretax equivalent annual incomes per acre and their standard deviations for 160-acre tracts of site 80 cutover land.



of the standard deviation of an observation, and the standard error of the standard deviation estimate is about 12 percent. Such confidence intervals would be small rectangles around each point. The size of these rectangles of uncertainty are shown for 1 and 2 standard deviations around several points. Thus it is evident that most of the adjacent points are not significantly different from each other. For practical purposes, for one management regime to be distinctly superior to another, the difference in annual incomes must exceed 20 percent.

The degree of variation in management regimes also concerns the selection of the regimes for best rotation age, basal area to be retained in thinning, and other factors. This study finds that variations in annual returns are much more important than even the choice of rotation length of basal area guides based on maximum annual incomes or rates of return.

Making decision rules concerning the tradeoffs between these management regimes is particularly difficult. For all of these alternatives the distribution of returns is not normally distributed. For all of them, returns that do not cover costs is a distinct possibility. Thus if an investor was absolutely conservative--he was willing to take few if any chances--he would not invest in timber growing.

The trade-off or indifference curve for deciding between different points on the mean-variance scatter diagram depends on the investor's willingness to take chances. This in turn is likely to be influenced by his other investments and the degree that he is dependent on this particular investment for income

and capital growth. The combination of various investments into portfolios--which is generally called portfolio or Markowitz theory--is generally beyond this study.

But a general rule for the tradeoff would be useful for the consideration of alternative management regimes. The various indifference curves suggested in the literature (Sharpe, 1970) are adapted to the special characteristics of rate-of-return and capital growth of investors. Investors indifferent to risk would have horizontal indifference curves. If investors wanted to be 83 percent sure that their incomes would be higher than taking no risks, no alternative would be chosen below a 45 degree line from the origin. A more moderate willingness to take risks--2/3 chances over a no-risk alternative--may be more typical. This is shown by line A-B in figure 1. Latane and Tuttle (1967) suggest another form of indifference curve:

$$k = I^2 - \sigma^2$$

where E is expected income and T is the standard deviation. For the point for management level VI - E, the curve is shown by line B-C in Figure 11.1. The general slope does not differ greatly from that of a 2/3 risk preference given by A-B but the curve becomes much steeper as the expected income declines.

Interpretation of results. Figure 11.1 can be used to determine management regime to be followed for site 80. Management levels I and II are quite inferior and would not be chosen by a prudent owner. The returns from plantations are not significantly higher than natural stands and the risk sufficiently larger so that either

management level III or IV (using natural regeneration) seems preferable if the seed sources for natural regeneration are present. Availability of genetically improved planting stock would undoubtedly make plantations preferable than natural stands.

Whether either natural stands or plantations are thinned or not has complex relationships. Thinning plantations raises the average expected income substantially, largely because it enables the trees to grow into sawtimber size. But thinning also increases the variations in returns, primarily from increased fire and insect risk. (The Fomes annosus problem, if recent technology was not used, would still further increase risk.) Many conservative owners would hesitate to thin plantations. Thinning of natural stands seems to reduce the expected annual income without affecting the variability of returns substantially. Therefore it appears as if management level IV would also not be chosen under the assumption used.

Results for owners of small tracts. Financial returns for small privately owned tracts are affected by two opposing factors. First is the effect of the federal income tax provisions allowing the owner to expense immediately a large proportion of his expenses. He pays federal income taxes at only capital gains rates on nearly all the proceeds from growth.[1/] The second force results from

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1/From the number of taxpayers that file the special federal timber tax forms, it is evident that either most small landowners do not know or take advantage of the timber provisions, and thus pay income taxes at ordinary income rates, or do not report income from timber sales at all.

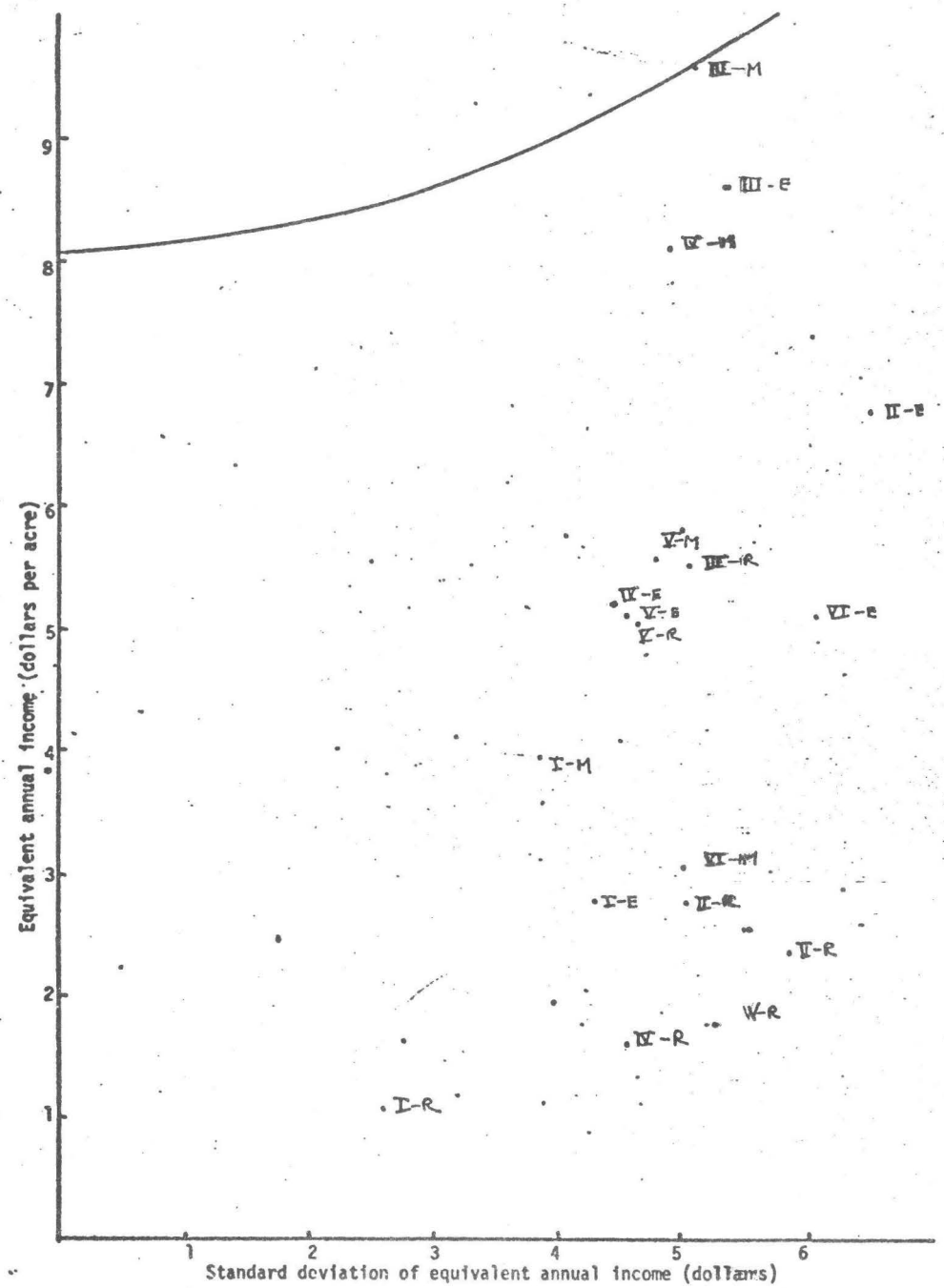
the diseconomies of scale or small tracts, which in the program takes the form of fixed costs for both treatments and for sales of timber. Losses from fire are also assumed to be higher for small tracts because their greater perimeter exposes them more frequently to occurrences of fire, nearly all of which are man-caused.

At about 80 acres in size, the tax and size factors seem to counter balance each other. Figure 11.2 shows the alternatives for a 80 acre tract. Below 80 acres the annual returns become increasingly smaller and fewer management regimes offer net income at the owner's guiding discount rate. For tracts of 20 acre size, only the intensive management of natural stands yields positive returns, and for 10 acre tracts no management regime offers an acceptable investment opportunity. For more productive sites, the break even point for management occurs on smaller tract sizes than for site 80 land.

Management of natural stands on cutover sites seems to have a substantial advantage over plantations for most small owners, largely because of the heavy fixed costs of site preparation and planting. A major limitation for many small owners is that sources of seed for natural stands may not be present, so new stands would have to be planted.

If the area has a high fusiform rust infection rate, returns from plantations are definitely inferior to natural stands. With genetic improved planting stock, plantations appear to be competitive with natural stands for tracts of 80 and even 40 acres. For smaller

Figure 11.2--Management alternatives ranked according to after-tax equivalent annual incomes and their standard deviations for 80-acre tracts of individually owned site 80 land.



tracts plantations are at increasing disadvantage.

Returns for large sized tracts. For tracts larger than 80 acres the incentives from the income tax provision offset the effect of size (based on 160 acres for the pretax simulations). For the corporate ownerships (owner type 7) the annual income per acre is more than doubled, as shown in figure 11.3, though the variance of that income is less than doubled.

Compared with the results for site 80, the position of all plantation regimes improves with respect to annual income and variability, relative to returns from natural stands. There are smaller differences in variability between alternative regimes, nearly all of which have a standard error of from 5 to 8 dollars per acre. With low cronartium infection rates, or control of cronartium through overplanting and precommercial thinning, the best plantation regimes and natural stand regimes are approximately equivalent.

Using the annual income as a criterion, the lower management regimes of I and II are decidedly inferior, and yield only a small part of potential income for the owner.

Returns for site 60 land. Without the incentives of the federal income tax provisions, the management of site 60 land is marginal for all owners (table 11.4 and figure 11.4). Management of level I, paying only property taxes, would give an annual income of $1 an acre on the average, though about 20 percent of the time small tracts would produce no income at all. Intensive management of natural stands just pays about 5 percent on the investment.

Figure 11.3--Management alternatives ranked according to after-tax equivalent annual incomes and their standard deviations for 320-acre corporation-owned tracts of site 80 land.

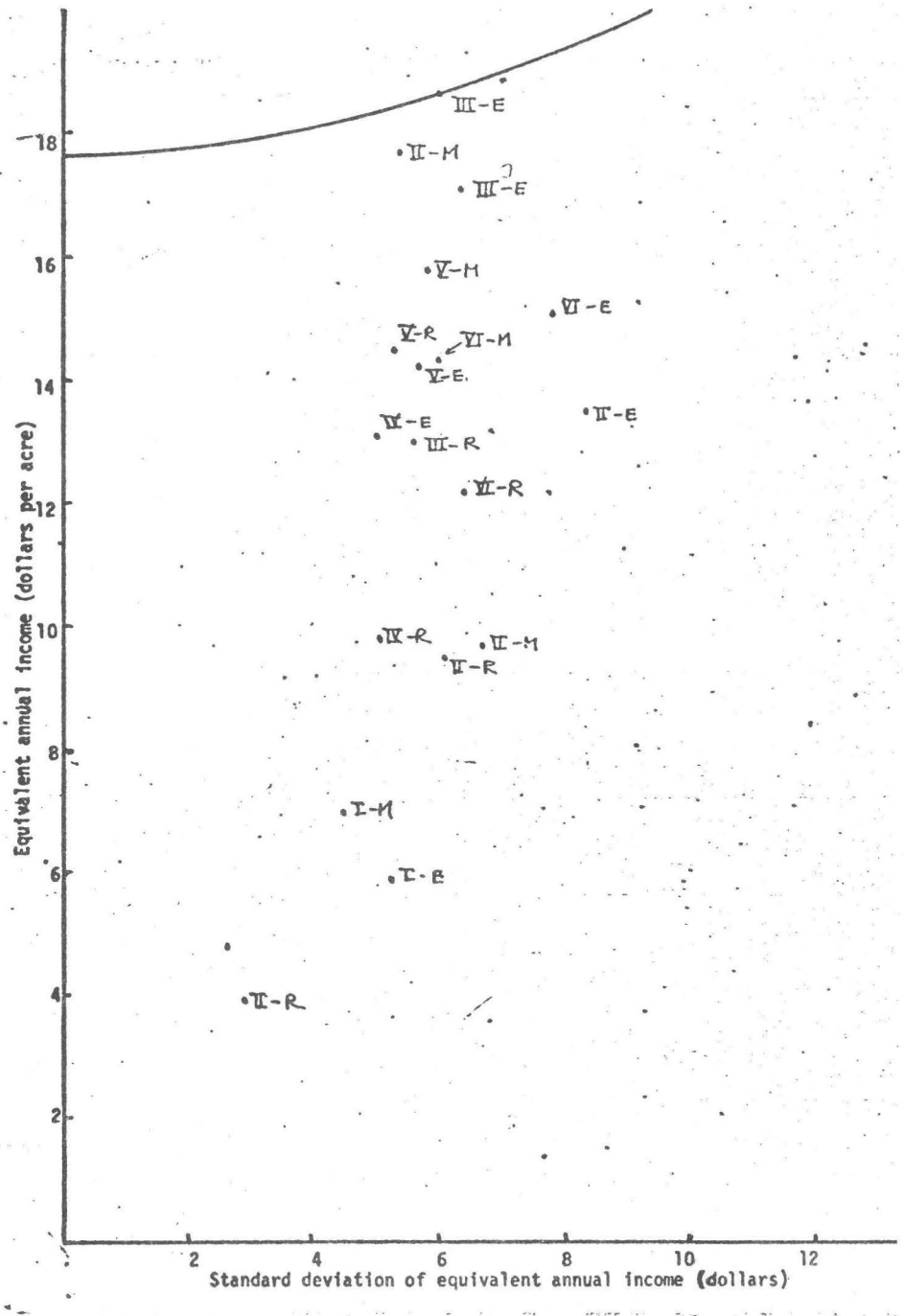


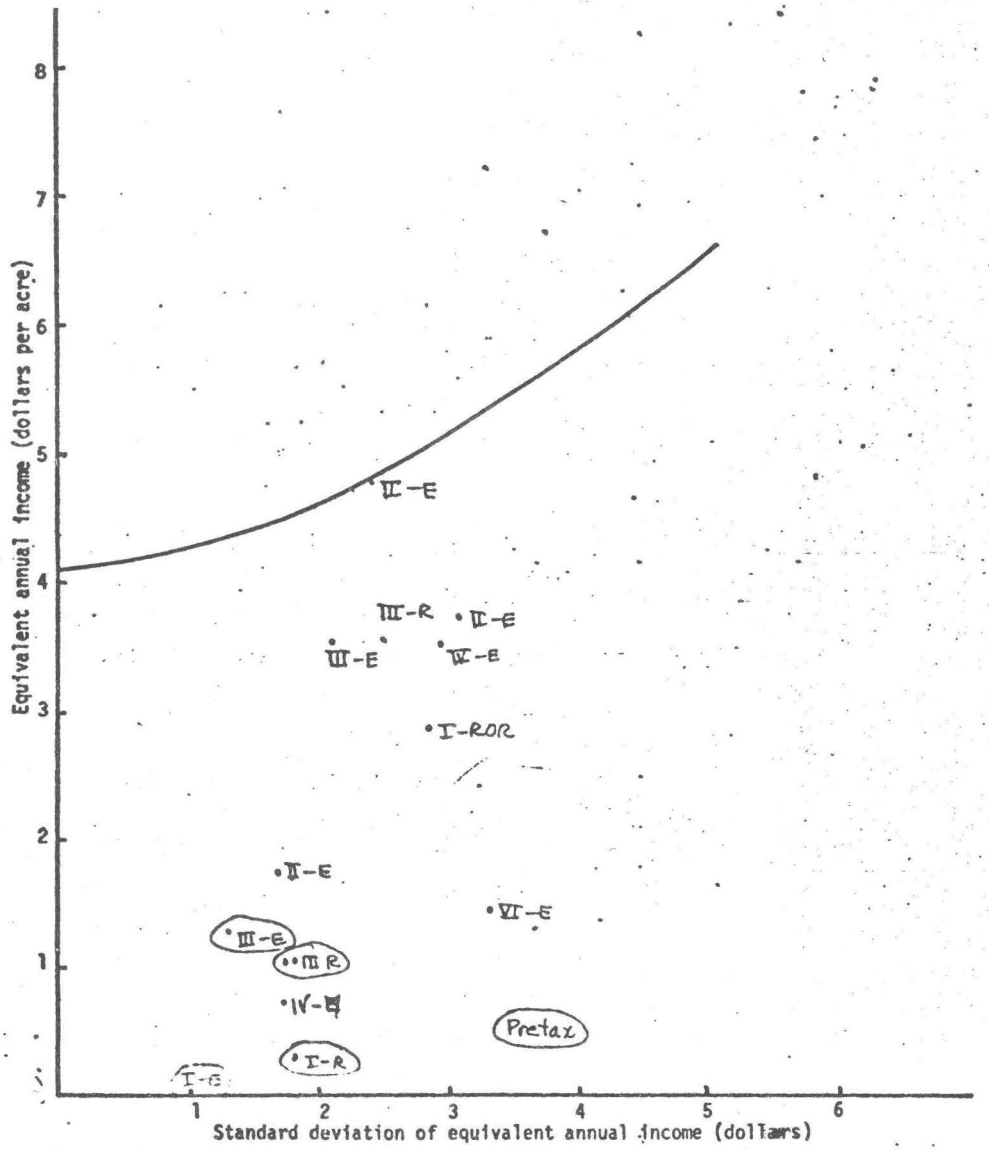
Table 11.4--Mean annual incomes and their standard deviations before taxes and for owner situations 4 to 7 for site 60 cutover land.

Management option 1/	Pretax		Owner 4		Owner 5		Owner 6		Owner 7	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
	(Dollars per acre)									
I-E	.16	.96	-.06	1.66	.82	1.46	1.39	1.34	1.76	1.67
R	-.31	1.09	-1.00	1.75	.11	1.50	.84	1.36	1.07	1.70
II-E	.30	1.71	-1.58	2.68	1.31	2.53	2.82	2.47	3.76	3.10
R	-.05	1.60	-2.25	2.64	.61	2.38	2.06	2.27	2.85	2.84
III-E	1.30	1.28	-.78	2.03	2.16	1.92	3.65	1.92	4.82	2.39
R	.57	1.51	-2.09	2.33	1.05	1.88	2.59	1.71	3.56	2.08
IV-E	.02	1.62	-2.62	2.76	.77	2.46	2.60	2.36	3.53	2.94
R	-1.63	1.07	-5.21	2.10	-1.61	1.67	.31	1.46	.69	1.79
V-E	-1.97	1.28	-5.99	2.31	-2.31	1.99	-.45	1.86	-.22	2.31
R	-2.55	1.13	-7.35	2.00	-3.28	1.61	-1.27	1.45	-1.18	1.78
VI-E	-.78	7.19	-5.45	2.96	-1.30	2.76	.86	2.68	1.47	3.35
R	-3.23	1.61	-8.72	2.48	-4.33	2.21	-2.03	2.10	-2.12	2.63

1/ E indicates alternative chosen within a management level because they had highest equivalent annual incomes, R because they had highest rate-of-return. Compromise situations were not made.

The symbols $\bar{x}$ and σ indicate average and standard deviation respectively.

Figure 11.4--Management alternatives ranked according to pretax equivalent annual incomes per acre and their pretax standard deviations for 160-acre tracts of site 60 land.



Under no circumstances does management of site 60 land in tracts 80 acres and smaller appear to return 5 percent, even with the tax advantages. For large owners income tax provisions and lower costs of treatments make intensive management of natural stands on site 60 land reasonably rewarding. The best regimes are unthinned stands with intensive site preparation, which yields relatively high volumes of pulpwood sized timber.

Results for site 100 land. Equivalent annual incomes for site 100 land are substantially higher for all management regimes than for site 80 land (figure 11.5 and table 11.5). The clear choice using the annual income criterion is plantation management. Unthinned plantations give approximately as much income as thinned plantations, but less variability of returns. Unless the owner prefers one product the decision would be up to the owner's coin toss, with little advantage among the criteria assumed.

For small owners the benefits from the income tax provision outweigh the disadvantages for smaller tracts for regimes as small as 40 acres, and some management seems possible as low as 10 acres. For the cautious small owner, natural stand management under intensive site preparation without thinning offers moderate returns with relatively little chance of loss. The data are shown in figure 11.6 for 80 acre tracts.

In high fusiform rust areas, plantation management yields relatively high returns but has very high variation of returns. If the fusiform rust problem is minimal, plantation management would be much preferred by most owners, as it offers quite high

Figure 11.5--Management alternatives ranked according to pretax equivalent annual incomes per acre and their standard deviations of 160-acre tracts of site 100 land.

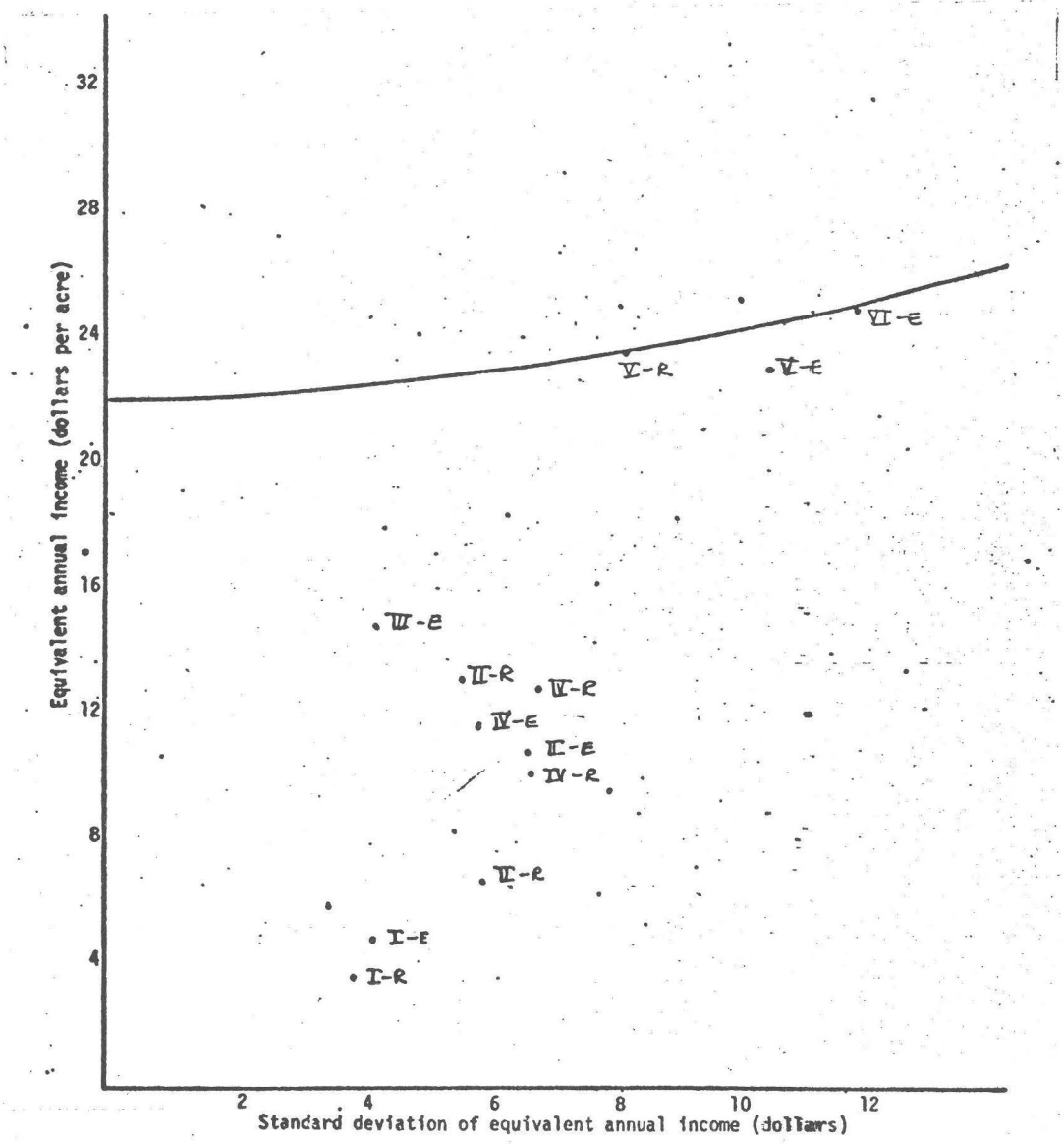


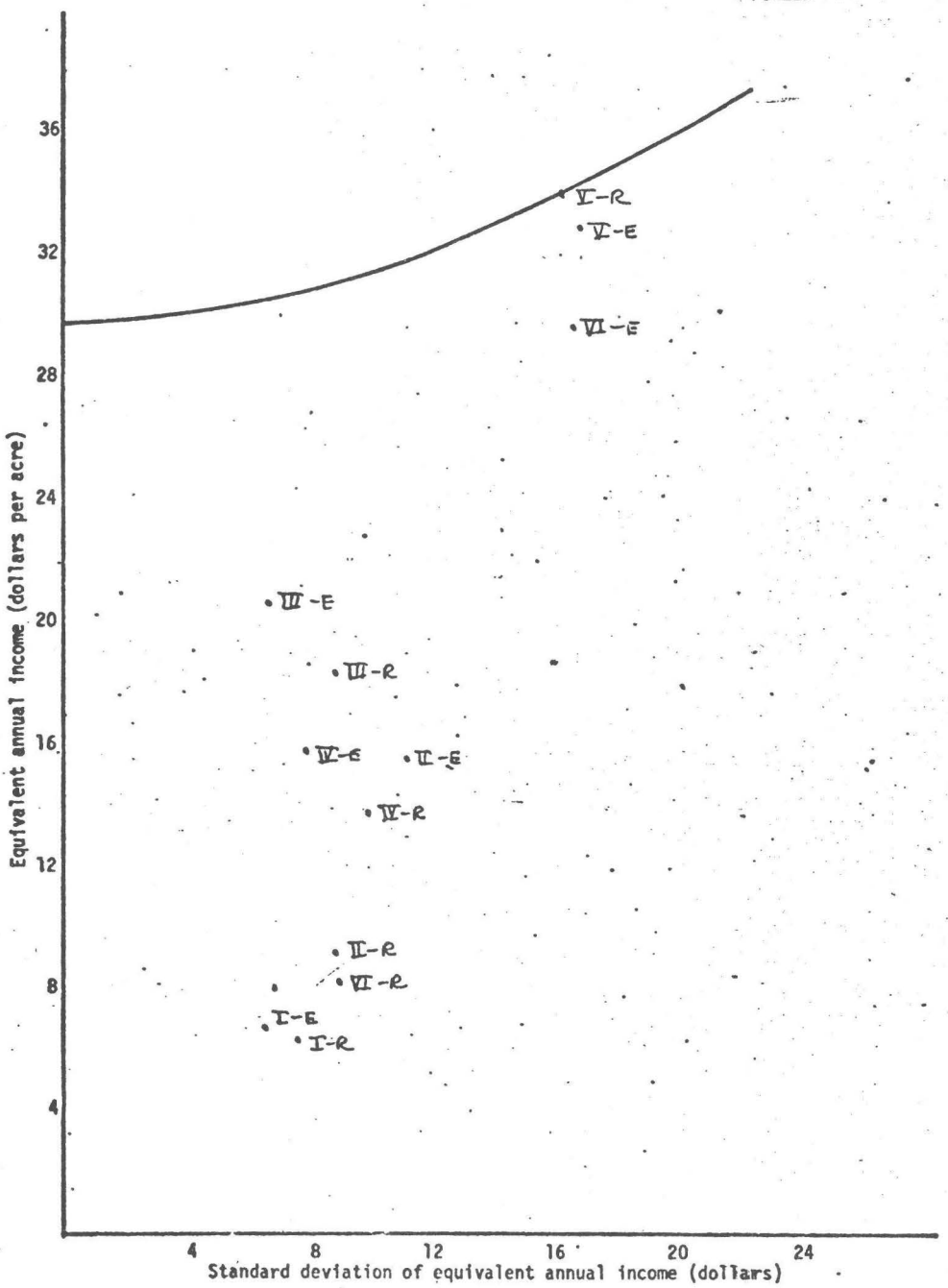
Table 11.5--Mean annual incomes and their standard deviations before taxes and for owner situations 4 to 7 for site 100 cutover land.

Management option 1/	Pretax		Owner 4		Owner 5		Owner 6		Owner 7	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
	(Dollars per acre)									
I-E	4.43	4.02	6.83	6.40	8.06	6.28	9.12	6.18	11.35	7.73
R	3.84	3.78	6.06	6.16	7.38	5.99	8.49	5.85	10.58	7.33
II-E	10.67	7.26	15.38	10.99	18.45	10.80	20.36	10.67	25.62	13.35
R	6.94	5.71	9.05	8.63	12.20	8.53	14.07	8.46	17.81	10.58
III-E	14.59	4.18	20.68	6.41	23.80	6.31	25.65	6.28	32.26	7.85
R	13.15	5.52	18.32	8.74	21.64	8.37	23.56	8.21	29.68	10.22
IV-E	11.47	5.79	15.87	7.85	19.40	7.84	21.60	7.91	27.19	9.85
	12.94	6.58	13.73	9.53	18.59	9.28	21.35	9.16	27.08	11.43
V-E	22.67	10.36	32.56	16.54	36.63	16.43	38.95	16.36	48.99	20.45
R	23.20	8.02	33.33	13.52	37.93	13.49	40.51	13.49	51.01	16.87
VI-E	24.46	11.68	29.36	16.20	34.02	16.09	36.69	16.05	46.23	20.06
R	10.17	6.55	8.21	8.61	13.32	8.15	16.28	7.85	20.74	9.81

1/ E indicates alternative chosen within a management level because they had highest equivalent annual incomes, R because they had highest rate-of-return. Compromise situations were not made.

The symbols $\bar{x}$ and σ indicate average and standard deviation respectively.

Figure 11.6--Management alternatives ranked according to pretax equivalent annual incomes per acre and their standard deviations of 80-acre tracts of individual-owned site 100 land.



returns for even small acreages with relatively little risk.

For large corporate owners (figure 11.7) the return possibilities for site 100 land on large tracts are highly rewarding. The equivalent annual income per acre for some regimes, even after adjustments for loss, exceed $50 per acre per year. The best alternatives are nonthinned plantations on short rotations or thinned plantations on a relatively long rotation.

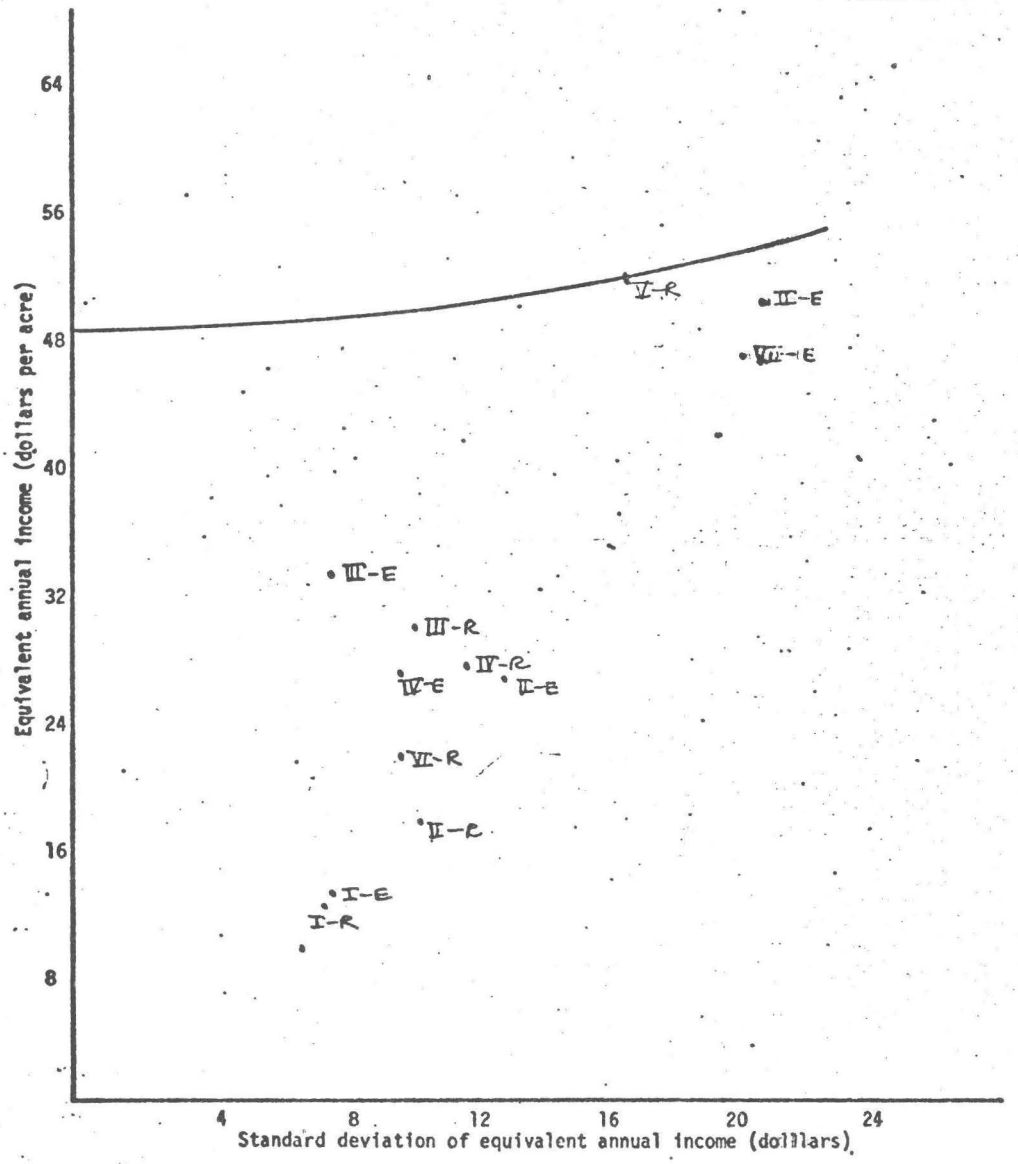
Management levels I and II are inferior in all respects. Management levels III and IV offer medium income with moderate risks, but yield approximately half the income that would be expected from plantation management.

Returns from open-field and converted hardwood types

A limited series of stochastic simulations for management alternatives on open-field and converted hardwood land showed much the same patterns as was found with the deterministic situations. The simulation of the variance was incomplete, however, since the management regime changes to cutover land after the first rotation, and the variance during the succeeding rotations could be expected to follow a somewhat different pattern than with first rotations.

Of particular importance is that the returns from open field management regimes were not only much higher than with cutover land, but that the variance was lower. The impact caused by establishment success or plantation survival was smaller than on cutover land. Most important, however, was the absence of uncertainty in the cost of site preparation.

Figure 11.7--Management alternatives ranked according to pretax rates-of-return and their standard deviations for 320-acre tracts of corporation owned site 100 land.



For converted hardwood type management regimes, annual incomes were much lower, as expected. The large cost for removal of the hardwood, which has unusually large variation, caused the standard error of returns to increase sharply. For many owners, particularly of small tracts, the added risk of high costs of conversion would be a definite deterrent to investment in conversion of degraded hardwood land to pine plantations.

Rate-of-return as an investment criterion

Chapter 3 discusses the theoretical arguments that led to favoring equivalent annual income (or present net value) as the major criterion for selecting the best management regime in timber growing. These were: (a) land is the primary constraint on increasing income, and that owners can borrow additional needed capital or can invest surplus capital in other types of investment at his guiding rate, (b) for most owners rate-of-return calculations should include the value of the land in the investment base in addition to cash outlays, and land values are generally unavailable or dependent on present net worth calculations[2/].

On theoretical grounds it was shown that use of rate-of-return instead of equivalent annual income should favor short rotations instead of long ones, light basal area after thinning rather than

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2/These objections to use of rate-of-return for selecting the major management regime, do not apply with equal force to use of rate-of-return to judge whether to make additional investment within the management regime selected. For such suboptimizing purposes it generally makes little difference which criterion to use since the results are highly correlated (Webster, 1965).

heavy, and low investment per acre rather than intensive timber management. In Chapter 10, these conclusions were found to hold in selecting management regimes using deterministic simulations. In stochastic simulations, however probabilities of loss are influenced directly or indirectly by most management parameters.

To determine the effect of the variability of growth, costs, prices and losses, the simulation program computed rates-of-return on the investment without land values for all of the simulations for cutover land. The results are presented in table 11.6. Figure 11.8 shows the scatter of rate-of-return--standard error points for the pretax results comparable to the points shown in figure 11.1.

Nearly all of the rates-of-return are between 6.5 and 8.0, with the variance of estimates in an equally narrow band from 1.9 to 2.2 percent. The only major exceptions to the pattern are the results from level I unmanaged stands, which had, as expected, much higher variation. The results, however, are generally the same. Because planting and spraying costs add to the investment base, and losses from fire, storm, and insects are high, returns on the investment in planting are only equivalent to the guiding rate-of-return.

Within levels of management, only slight differences in rates-of-return are caused by rotation length, or basal area to be retained in thinning. The effect of the diverse types of variation is to destroy or overwhelm the sensitivity tests for these management parameters.

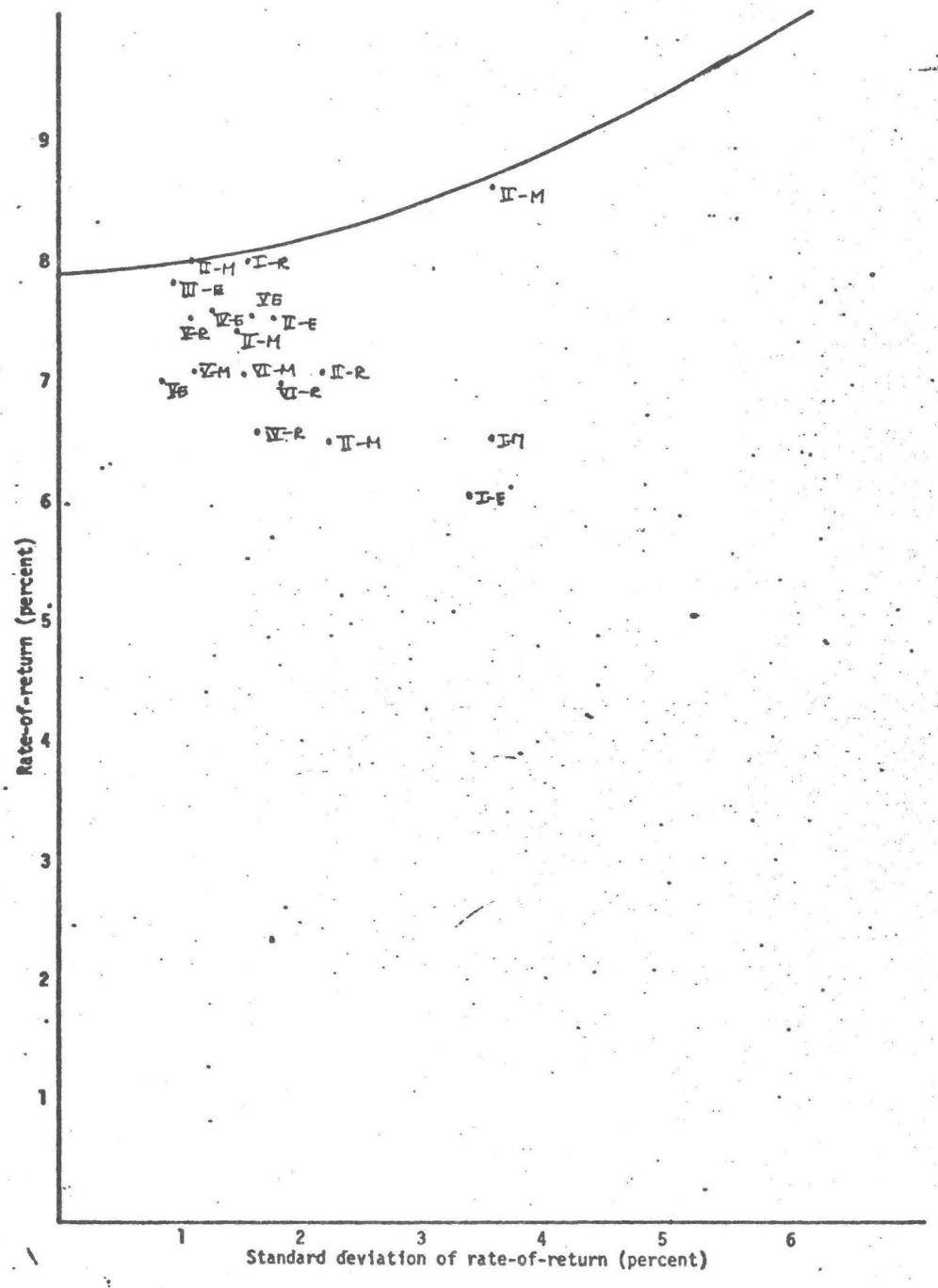
Inspection of the rates-of-return and their standard errors for

Table 11.6--Mean rates-of-return on investment and their standard deviations before taxes for owner situations 4 to 7 for site 80 cutover land.

Management option 1/	Pretax		Owner 4		Owner 5		Owner 6		Owner 7	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
	(Dollars per acre)									
I-E	6.03	3.35	6.01	3.41	7.46	3.21	8.90	3.21	8.87	3.20
M	8.56	3.34	8.38	3.36	10.00	3.32	11.83	3.30	11.79	3.29
R	6.49	3.52	6.11	3.50	8.06	3.64	10.23	3.83	10.20	3.82
II-E	7.49	1.75	6.62	1.85	7.88	1.75	8.78	1.68	8.93	1.68
M	6.42	2.20	5.45	2.15	6.92	2.05	8.01	1.98	8.16	1.99
R	7.04	2.17	5.74	2.20	7.37	2.16	8.59	2.05	8.77	2.06
III-E	7.78	.97	6.90	1.02	8.01	1.00	8.80	.99	8.93	.99
M	7.96	1.11	7.19	1.16	8.40	1.26	9.27	1.34	9.40	1.34
R	7.92	1.56	6.80	1.47	8.26	1.47	9.26	1.46	9.42	1.46
IV-E	7.52	1.29	6.61	1.27	7.99	1.31	9.00	1.35	9.13	1.34
M	7.48	1.42	6.56	1.34	7.80	1.35	8.83	1.40	9.02	1.46
R	6.56	1.61	5.53	1.59	7.21	1.62	8.50	1.63	8.66	1.63
V-E	6.99	.83	6.00	.86	7.14	.81	7.91	.78	8.04	.77
M	7.05	6.10	6.16	1.01	7.45	1.02	8.36	1.03	8.50	1.03
R	7.48	1.08	6.39	1.07	7.89	1.00	8.86	.96	9.04	.96
VI-E	7.50	1.43	6.03	1.24	7.32	-1.24	8.24	1.24	8.39	1.24
M	7.03	1.50	5.60	1.32	7.04	1.30	8.10	1.30	8.20	1.30
R	6.92	1.66	5.36	1.41	6.90	1.45	8.01	1.48	8.18	1.49

1/ E indicates alternative chosen within a management level because they had highest equivalent annual incomes, R because they had highest rate-of-return, and M are compromise alternatives. The symbols $\bar{x}$ and σ indicate average and standard deviation respectively.

Figure 11.8--Management alternatives ranked according to pretax rate-of-returns and their standard deviations for 160-acre tracts of site 80 cutover land. Data is comparable to that for figure 11.1.



other owners and for other site indexes shows a similar bunching of rates-of-return estimates and a quite narrow range of standard errors. In fact, for management levels III and higher, the standard error of rates-of-return are between .9 and 1.5. In addition they seem to be highly correlated with length of rotation, with the standard error of short rotations mostly between 1.2 and 1.5 and the standard errors of long rotations nearly always from .8 to 1.3. The variances for site 60 land seem to be somewhat narrower, and those for site 100 land a little broader than the range given for site 80.

Thus the use of mean-variance analysis for forest investments using rates-of-return as the criterion seem to be highly insensitive to the management parameters involved. Overall, the effect of the use of rate-of-return as a criterion would be quite conservative because the same rate of return could be obtained with less investment if short rotations, light reserve basal areas, and less intensive management alternatives were chosen. On a regional basis the result would be smaller inventories, lower rates of growth per acre, and reduced timber supplies.

Summary

This chapter presents the results of stochastic simulation in the evaluation of the impacts of individual types of variation, and of all types of variation upon the selection of management regimes for the growing of southern pine.

Variation in growth processes was found to have a slight

upward biasing effect on expected returns, variation in costs and prices essentially a neutral effect on expected returns, and losses from fire, storm, insects, and disease a sharp downward effect on average returns. Cronartium rust was found to be of particular importance in southern pine plantations and a modification of the plantation management level was introduced to reduce the impact. All general types of variation have substantial impacts on the risk of timber growing investments.

The results from simulations of management regimes on cutover land are highly suitable for display and analysis using the mean-variance approach. This permits the selection of the best regime for each site, condition class, and owner type. Applied to the loblolly pine management situation used in the study, the following general conclusions were reached.

1. With high incidence of cronartium rust and no management modification, management of natural stands produced about the same income but lower variance than plantation on site index 80 or less, and would thus be preferred. With low cronartium incidence or management modification, plantation management would be superior on site 80. On site 100 lands thinned or unthinned management of plantations would be best regardless of cronartium infection risk. The use of genetically superior stock would further favor plantations.

2. The federal income tax provisions affecting taxes on costs and capital gains treatment cause a substantial increase in relative returns from timber growing. For owners of large

acreages the tax provisions permit a nearly doubling of the effective annual income per acre.

3. The effect of size of tract on the annual income from growing timber is particularly sharp for tracts of less than 80 acres. Intensive management of site 60 land in small tracts is not economic under almost any circumstances though management of large tracts under the tax incentives is profitable for large owners and corporations.

4. Lower levels of management--with or without low site preparation and lack of hardwood control--is inferior to more intensive management under nearly all circumstances.

Using rates-of-return as the investment criterion instead of equivalent annual income (or present net worth) caused a sharp narrowing of the distinctions between alternatives, and a blurring of the differences between management regimes. This adds weight to the theoretical objections to the use of rate-of-return in the evaluation of forest management alternatives.

Chapter 12

SUMMARY AND CONCLUSIONS

This study develops and demonstrates a new approach to evaluating forest investment decisions and management regimes. The approach combines the traditional concepts of financial maturity with the techniques of stochastic simulation. Sufficient biological, cost, price, and risk information were developed from existing primary and secondary sources to simulate a range of hypothetical timber management regimes for one of the southern pine species--loblolly pine. The findings from simulations of seven levels of management suggest that many aspects of the conventional wisdom in managing southern pine may be erroneous.

Assessment of methodology

The evaluation model

The study required development of a specialized computer system to simulate the development of stands of timber on specified tracts of land. This system incorporates a mathematical model of both biological and economic relationships. It can be easily adapted to other forest species and management situations. The major features of this model are:

1. Routines for the major existing techniques for projecting growth of timber on an aggregate stand basis, and means to select the most appropriate technique as the simulated timber stand develops.

2. Routines that simulate all of the major current timber growing practices such as site preparation, planting, thinning, and harvest cuts, and simulate within probability distributions the success of natural regeneration and planting.

3. Cost and price estimation procedures sensitive to the attributes of the simulated timber stand and to the owner's intended level of management. The cost and price procedures also estimate the variance of expected values and, if specified, will randomly vary any cost or price within a probability distribution. Both levels and rates of change over time can be varied.

4. Fire, storm, insect, and disease loss generation techniques which randomly simulate occurrences of losses, size of area affected, and severity of damage according to interrelated probability distributions. The impact on the attributes of the timber stand are estimated and salvage value, if any, computed.

5. Tax payment simulation according to the special provisions of federal income tax regarding timber. Within a given stand simulation the after-tax revenues and costs can be computed for four different tax situations. Property taxes are handled as other costs.

6. Reduction of the stream of income and costs to measures of financial gain, such as equivalent annual income per acre, present net discounted value, or rate-of-return on investment. These can be computed for specified planning horizons (including intentions to grow timber perpetually), and with or without including the owner's estimate of land value.

Development and testing of the model proved that the method of analysis can provide the necessary simulated data to appraise any of the current or foreseeable levels of management. No technical problems appear to limit the application of the model to the uses envisaged in its design. The realism of the simulated timber management regimes exceeds that from any other presently developed means of analysis of the economics of timber growing.

The model concept and the procedures for estimating timber growth, costs, prices, risks, and income taxes were designed to provide information at an acceptable level for reasonable decision-making by forest owners or managers. This level of detail, however, required a complexity within the computational system that was several times greater than anticipated. In terms of size, input requirements, and operating costs, the program became a major computer system package.

Adaptation of biological process functions

This study chose for the biological aspects of the model a level of detail--the aggregate stand approach--that was adaptable to most of the growth, yield, and loss information available. This level of detail appears to provide adequate sensitivity to the management decisions to be made, and is comparable to the level of accuracy of costs, prices, losses from natural causes. At this stage of development the model would likely gain little from greatly increased detail of modeling growth processes of normal timber stands.

The model would benefit, however, from substantially improved distribution functions of losses from fire, storm, insects and disease, growth responses to these losses and other major disturbances

such as thinning, hardwood control, and harvest. The model is also capable of incorporating routines to estimate yields from associated multiple-use products such as forage growth, wildlife populations, and water yields.

Methods of deriving cost and price functions

Stochastic simulation of timber growing requires functional predicting equations of great sensitivity to many values. Means to fit regressions to a near optimal weighting system and to describe the pattern of variance around predicted values are needed. A technique and special computer progression program was developed for this study to fit regression equations by an iterative weighting process, each iteration using the pattern of variance developed from the previous iteration.

The procedure successfully analyzed the data, though the results seemed similar, and not strikingly superior, to regression equations fitted by weighting the observations by the pattern most evident in scattered diagrams of data. The technique does provide excellent estimates of the relationship of the variance of predicted value to the predicted value. This concept was employed successfully in the simulation of random variations of costs and prices within probability distributions dependent on the estimated values.

Implications for southern pine management

With the possible exception of proprietary data developed by large forest products firms, growth and yield data such as used in this study are the basis for all previous economic analyses and management

decisions in southern forestry. The stochastic simulation approach permits the incorporation of greater detail and flexibility in treatments, costs, and prices, and allows consideration of losses from fire, storm, insects, and disease. With this added information, the economic analysis of timber growing management regimes takes on additional aspects of realism. The results of the simulations used to demonstrate the approach suggest the following conclusions relative to the conventional wisdom of forest management in the South.

1. Aspects of management strategies related to losses from natural agents, costs of treatments, and income tax provisions influence financial returns more than the optimum levels of the traditional management parameters--rotation age and basal area after thinning. In terms of the variation that can be expected in either annual income or rate-of-return on investment, the differences between the best and next best rotation ages or levels of growing stock are either insignificant or marginally significant.

2. Impacts on annual income caused by losses from natural agents are several times more important than the physical losses in yields in cubic feet of wood. The stochastic loss generation technique, even to the extent developed in this study, provides a sensitive means to measure the impacts of various types of losses and of potential management action to reduce occurrence and severity of damage.

3. The provisions of federal income taxes regarding timber tend to increase annual incomes from forestry investment over pretax levels. They greatly increase the benefits from forest management relative to other productive processes that are taxed as ordinary income and that do not allow mismatching of costs and revenues over time. The cost

expensing and casualty loss provisions of the tax laws may be relatively more important than the privilege of taxing income as capital gains.

4. Effects of tract size on the annual income per acre from forest management are dramatic. The analysis of both primary cost and price data established the relative size of the fixed costs per acre incurred in timber growing treatments and sales of timber. These fixed costs cause diseconomies of scale that severely limit the level of management profitable on small tracts, and eliminates income from lands of low productivity. The effect of the fixed costs of treatments seem to be more important than the fixed costs of making timber sales and removing timber.

An additional aspect of small tract sizes is that it increases the variability of returns. Using the special analyses of residuals found in fitting the cost and price regression equations, means were developed to estimate this variability by tract or project size. Small tract size also increases risks from loss, particularly fire.

5. Several common practices in southern pine management, particularly thinning and planting, are not markedly advantageous. The reasons for less expected incomes developed by this study for the lack of gain from these treatments are not those usually mentioned in discussions of their pros and cons. The advantages of thinning are reduced by the low prices (resulting from high fixed costs) received for the thinned material. The advantages of planting, particularly on cutover land, is reduced by the costs of site preparation and locally high incidence of fusiform rust. Because of losses and variable costs, both thinned and planted stands appear to have more variable returns

than unthinned natural stands established on intensively prepared sites.

Implications for southern timber supply

A number of conclusions concerning the regional timber supply in the South are suggested by the results of the simulations in this Study. These are:

1. Since site index 60 land is economically submarginal or marginal for all but large tracts, all or nearly all land with less than 60 site productivity in the South is not suitable for active forest management. As presented in Chapter 2, such land comprise 29.7 million acres, or 19.2 percent of total area in forest types in which southern pine can be grown.

2. The profitability of intensive management on site 80 and site 100 land is highly dependent on tract size. According to the best information (U.S. Forest Service 1958), about 19 percent of forest in the East is in ownerships of less than 75 acres in size, 9 percent in ownerships less than 40 acres and 4 percent in ownerships less than 20 acres. If similar proportions of land are of marginal productivity for timber growing in the 60-80, the 80-100, and greater than 100 site index classes, an additional 18.3 million acres (11.8 percent of area) is not economic for forest management.

3. On the remainder of the acreage, intensive managment of at least natural stands is usually more economic for all but the small ownerships if the management criterion is the equivalent annual income per acre. In particular, site preparation to some extent after harvesting is nearly always financially rewarding.

4. Because of the disadvantages of small tract sizes, there is great incentive for institutional arrangement to put small tracts and ownerships under forms of management that reduce costs of treatments. Such arrangements are leasing to large ownerships or forestry industry, pooled management by consultants or by cooperative institutions, or pooled treatment of forest lands. Trends toward the formation of such programs are already evident in the South.

5. Programs to reduce losses from natural agents may have two advantages that would increase timber supplies. The most obvious, the reduction of physical volumes of losses may not be the most significant. In the long-run reduction of risk of investment may be more important, since it may lead to the active management of substantial acreages that are presently too risky for intensive timber growing. Similarly the widespread availability of genetically improved stock may have a double effect of increase yields on presently planted areas, and of extending the area for which plantation forestry is economic.

6. For all but a few individuals, large tracts of uniformly spaced and dense timber is less esthetically pleasing than a mosaic of stand sizes, condition classes, and densities of timber, even when not broken with land in alternative uses such as row crops or pastures. Benefits from other multiple-uses, particularly recreation and wildlife are generally higher for small and medium sized tracts or clearcuts, rather than large areas. This study shows, however, that management of timber land in small tracts results in substantially lower per acre returns. The method developed in this study can be used to determine the opportunity costs of managing forest

lands for esthetic and environmental goals as well as timber income.

Appendix I

GLOSSARY OF FORESTRY TERMS

Age, investment--Growing seasons since initial purchase or investment in management, in this study assumed to be age from present.

Age, rotation--Growing seasons since previous regeneration cut, or reforestation if land was in non-forest use.

Age, stand--In natural stands, average age in annual growing seasons of dominant and codominant trees, but in plantations, growing seasons since trees were planted.

Basal area--Cross-sectional area in square feet of single trees or all trees in a stand measured 4.5 feet from ground.

Black terpentine beetles (Dendrotonus terebrans Oliv.)--A bark beetle that infests southern pine stumps and slash, and may spread to weakened or other live trees.

Board foot (of sawtimber trees or logs)--A measure of volume based on one of several log rules that estimate how much 1-inch lumber can be sawn from logs or trees.

Brush--Shrubs and small trees in understory of forest stand or occupying open land.

Canopy--The continuous cover of branches and foliage in crowns of trees in a forest stand.

Chaining--Site preparation treatment performed by drawing heavy anchor chain between two tractors, uprooting small trees and shrubs.

Chopper--Piece of equipment resembling a large drum with attached blades which churns up roots and cuts small stems of trees when drawn over area being regenerated by tractor.

Climax vegetation--The ecosystem or vegetation type toward which any earlier stage of succession will progress if unhindered by disturbance by man or natural catastrophy.

Commercial forest land--Land covered by tree species or once covered by tree species and capable of growing 20 or more cubic feet of utilizable wood per acre on a sustained long-run basis.

Controlled burning--Treatment that intentionally sets fire to forest in cool, calm weather to burn needles, leaves, branches and

brush on ground beneath the forest canopy. It reduces fuel and thus much of the danger from damaging wild fire.

Cord--Measure of wood volume in a stack of cut wood 4 feet deep, 8 feet long, and 4 feet high, or more generally the wood volume that would occupy 128 cubic feet if cut into 8-foot long or shorter bolts.

Cottonwood (Populus deltoides Bartr.)--A hardwood species with exceptionally fast growth on good bottomland soils in the South.

Cubic feet--Measure of solid wood volume normally measured inside bark of the main stem.

Cull tree--Tree in stand not meeting growing stock standards, either because it is rough, rotten, or of an unsalable species.

Cull tree removal--Treatment that removes cull trees in timber stands by cutting, girdling, or by application of chemical poisons by various means.

Cutover land--Land formerly covered by forest which has been harvested and the land has not yet regenerated.

Diameter (of tree)--Diameter of tree outside bark 4.5 feet from ground, professionally termed diameter breast high (d.b.h.). Diameter of stand is the average diameter of trees weighted by cross-sectional area, or tree of mean basal area.

Direct seeding--Treatment to obtain regeneration or establishment of a stand by broadcast or row sowing of tree seed treated with bird and rodent repellents.

Drainage--Treatment to reduce the average water table of land by digging ditches or canals at intervals of 100 or 5000 yards.

Ecosystem--Biological community of plants and annimals living in close proximity and forming an interrelated biological system. Forest types are generaaly considered as forming one or more ecosystems.

Fomes root rot (Fomes annosus (Fr.) Cke.)--Fungus that infects stumps of cut southern pine (and many other conifer) trees, and may spread from roots of cut tree to roots of live trees, killing them.

Forest industry--Firms or establishments operating primary wood processing facilities, which use wood in round log or bolt form.

Forest land--Land at least 10 percent stocked by forest trees of any size, or formerly having such tree cover and not currently developed for non-forest use.

Forest type--Broad class of forest ecosystems, dominated by species or

species groups mentioned in forest type name. Some 25 major forest types are recognized by the Forest Service's Forest Survey.

Fusiform rust (Cronartium fusiforme Hedgc. & Hunt.)--Fungus that infects young shoot tissue in southern pines, later forming cankers that girdle the stem. Canker will kill tree if infection is on or spreads to lower bole.

Genetic improvement (of forest trees)--Upgrading the inherent quality of a population of trees by a variety of methods, which may range from simple selection of seed sources to controlled crosses from selected superior parents.

Grade (of tree or log)--Classification that ranks quality or per unit value by external characteristics, usually size, knots, crook, and other defects.

Growing stock--Trees in stand meeting minimum specifications of quality and generally including trees presently or potentially salable.

Height (of tree)--Total height of tree in feet to top most bud. Height of stand is average total height of dominant or codominant trees in stand.

Herbicide--One of several chemicals used to poison vegetation by spraying or direct application. Most herbicides in forestry are selectively poisonous to hardwood trees and brush.

Inventory, timber--Volume of live timber growing on an area of land.

Ips engraver beetles (Ips spp.)--Bark beetles that infest the inner bark of dead and cut trees. They will occasionally also attack live trees, particularly ones under stress.

Management cost--Collectively the fixed costs of practicing forestry, including general planning and supervision, protection activities, and in most cases property taxes.

Merchantable timber--Timber which is currently capable of being sold and cut with a positive return to the landowner.

Nursery--In forestry, an area where tree seedlings are grown in beds for lifting and planting in areas being regenerated.

Overstory--Trees comprising the canopy of the forest, particularly the dominant and codominant trees.

Pales weevil (Hylobius pales Hbst.)--Insect that infests stumps of cut southern pine trees, and which will eat the bark from seedlings planted within a year of tree harvest.

Pine, loblolly (Pinus taeda L.)--Most common species of southern pine

group, ranging from Maryland to Texas in Piedmont and upper coastal plain.

Pine, longleaf (Pinus palustrus Mill.)--Species in southern pine group in coastal plain and sand hills from South Carolina to Louisiana with characteristic slow growth in juvenile grass stage.

Pine, slash (Pinus elliottii Engelm.)--Fast growing species in southern pine group that ranges from South Carolina to Louisiana in lower coastal plain. It is currently planted also in areas to the north of its natural range.

Pine, shortleaf (Pinus echinata Mill.)--Slow growing species in southern pine group found from New Jersey to Oklahoma, primarily in Piedmont and low mountainous areas.

Planting--treatment to obtain regeneration or establishment of a stand by planting seedlings grown in a nursery (for southern pine, almost always 1 year).

Poletimber--Live forest trees at least 5 inches in diameter breast high but less than sawtimber size.

Productivity class--Broad classification of forest land by potential cubic-foot volume growth per year over typical rotation. Forest Survey classes are: Less than 20, 20-50, 50-85, 85-120, and more than 120 cubic feet of wood growth per year.

Property taxes--Local and state taxes based on appraised value of land (and often timber). In this study it is assumed that there are no taxable improvements on the tract.

Regeneration or harvest--Cutting mature timber and subsequent establishment of new stands of seedlings in even-age timber growing.

Rotation--Period of time a stand is grown in even-age timber growing, after which the stand is harvested and regenerated.

Sapling--Live young tree from 1 inch to 5 inches in diameter breast high.

Sawtimber--Live forest trees of greater than specified diameter breast high (9 inches for southern pines in this study) and containing at least one 16-foot sawlog.

Seedbed--The type of ground surface on which seed falls from natural sources, such as bare soil, forest floor litter or duff, or brush.

Seedling--Live young tree from germination to sapling size--1 inch diameter breast high.

Silviculture--Science of the practices and management employed to grow trees, or more generally the timber aspects of forest management.

Site index--An alternative measure of land productivity specifically related to a particular species. It is expressed in expected height growth attained by index year (in East: 50 years for natural stands, 25 years for planted stands.)

Site preparation--Treatment of disposing of slash and brush, eliminating grass and other competing vegetation, and exposing mineral soil prior to natural regenration or planting. In this study, the cost of site preparation includes such treatments to insure regeneration after clearcutting. Similar but usually more intensive treatments are included in the cost of type conversion.

Slash--Tree tops, branches, and foliage left on surface of ground or in piles after logging operations.

Southern pine beetle (Dendroctonus frontalis Zimm.)--Bark beetle that attacks live southern pine timber in infestations that range from spots of a few trees to extensive areas.

Spraying, hardwood--Treatment that applies herbicide (such as 2,4,5-T or Silvex) to foliage of hardwoods to kill them. Pines are not normally affected.

Stand--An area of forest with relatively uniform composition, age, and density that can be managed as a unit under a single regime.

Natural stand--Stand established by seed dispersed naturally from nearby trees, seed trees, or already in place at regeneration.

Planted stand--Stand established by planting nursery grown seedlings.

Stand size--Broad classification of stands by dominant diameter class. Forest Survey size classes for pine stands are: 1-inch or less, seedlings, 1-5 inches, saplings, 5-9 inches, poletimber, over 9 inches, sawtimber.

Stocked (forest land)--Forest land with at least 10 percent stocking by standards for trees of varying diameter.

Stocking--Measure of degree to which forest land is occupied by live trees in relation to specified standards for trees of varying diameters.

Stumpage--The rights to cut standing timber, a frequent form of selling timber.

Thinning--Treatment of cutting by one of several methods of tree selec-

tion a portion of a stand, usually including the least desirable trees. The objective is to reduce basal area or stand density to prevent losses from endemic mortality and concentrate subsequent growth on fewer and higher quality trees.

Timber growing--Production of timber for harvest under a forest management or silvicultural regime.

Tree marking--Treatment of designating (usually with a paint-squirting gun) trees to be cut or left, whichever is most convenient.

Tract--An area of land of one legal parcel or contiguous legal parcels which is managed as a single unit.

Type conversion--Treatment that changes the species composition of a stand by clearcutting existing timber or destroying existing vegetation, preparing the site, and planting (or direct seeding) a different species. The cost of type conversion may include bulldozing, shearing, crushing, chaining, windrowing, or burning existing vegetation, and covers the costs included in site preparation.

Volume (of trees)--Net volume (in this study measured in cubic feet) in central stem of growing stock trees from stump 6 inches high to a point where central stem is less than 4 inches in diameter outside bark, or breaks in limbs.

Wildfire--Any fire occuring from natural causes or arson and not under control or forest owner or manager.

Yellow-poplar (Liriodendron tulipifera L.)--Fast growing, high quality hardwood species found on relatively moist, productive sites in the Piedmont and elsewhere in upper South.

Appendix II

SIMULATED MANAGEMENT REGIMES FOR CUTOVER LAND.

Table 1.--Management level I.

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 8	MAX HARV AGE				1	50.000	SITE INDEX			7	60.000									
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	15.	11.7	2.7	288.8	0.0	0.0												0.0	22.7
LEFT UNCUT	15.	28.	28.6	5.1	199.3	141.7	5.2												0.0	31.7
LEFT UNCUT	20.	37.	40.0	7.2	140.7	364.1	28.9												0.0	37.9
LEFT UNCUT	25.	43.	47.7	8.9	110.9	563.5	60.5												0.0	42.1
LEFT UNCUT	30.	48.	52.9	10.2	94.2	728.7	93.3												0.0	45.3
LEFT UNCUT	35.	52.	56.9	11.1	84.1	867.0	124.9												0.0	47.7
LEFT UNCUT	40.	55.	60.0	11.9	77.4	982.8	154.3												0.0	49.6
LEFT UNCUT	45.	58.	62.4	12.5	72.7	1080.2	181.4												0.0	51.1
COST 10	50.	3.77																		
HARVESTED	50.	60.	64.3	13.1	69.1	1162.7	206.1						64.3	13.1	69.1	1162.7	206.1	0.177	0.0	52.3
COST 2	0.	0.51																		
TRIAL 8	MAX HARV AGE				1	50.000	SITE INDEX			7	80.000									
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	20.	12.3	3.5	182.3	0.0	0.0												0.0	24.8
LEFT UNCUT	15.	37.	31.2	6.7	126.7	284.0	15.4												0.0	35.9
LEFT UNCUT	20.	49.	44.8	9.5	90.6	632.4	53.0												0.0	42.7
LEFT UNCUT	25.	58.	53.8	11.7	72.0	946.5	107.9												0.0	47.7
LEFT UNCUT	30.	64.	60.1	13.4	61.5	1205.8	180.1												0.0	51.4
LEFT UNCUT	35.	69.	64.7	14.7	55.0	1421.1	272.8												0.0	54.1
LEFT UNCUT	40.	73.	68.1	15.7	50.7	1599.2	374.4												0.0	56.2
LEFT UNCUT	45.	77.	70.7	16.5	47.6	1747.1	445.2												0.0	57.8
COST 10	50.	3.39																		
HARVESTED	50.	80.	72.8	17.2	45.2	1870.9	511.1						72.8	17.2	45.2	1870.9	511.1	0.273	0.0	59.1
COST 2	0.	0.76																		
TRIAL 8	MAX HARV AGE				1	50.000	SITE INDEX			7	100.000									
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	25.	13.0	4.3	128.7	43.8	0.0												0.0	27.3
LEFT UNCUT	15.	46.	34.4	8.4	90.5	449.4	23.6												0.0	40.2
LEFT UNCUT	20.	61.	50.6	11.9	65.8	966.0	76.3												0.0	49.1
LEFT UNCUT	25.	72.	61.8	14.6	52.9	1437.0	158.1												0.0	56.1
LEFT UNCUT	30.	80.	69.4	16.7	45.4	1824.6	270.4												0.0	59.4
LEFT UNCUT	35.	87.	74.8	18.3	40.8	2142.9	416.0												0.0	62.6
LEFT UNCUT	40.	92.	78.8	19.6	37.6	2402.3	596.0												0.0	64.9
LEFT UNCUT	45.	96.	81.7	20.6	35.3	2614.3	796.5												0.0	66.6
COST 10	50.	3.22																		
HARVESTED	50.	99.	83.8	21.4	33.6	2785.9	1017.6						83.8	21.4	33.6	2785.9	1017.6	0.365	0.0	67.3
COST 2	0.	1.01																		

Table 2.--Management level II.

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 8 MAX HARV AGE					1	50.000	SITE INDEX			7	60.000									
COST 4	0.	13.37																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	15.	20.8	2.5	589.3	0.0	0.0												0.9	13.8
COST 9	10.	1.56																		
LEFT UNCUT	15.	28.	43.6	4.7	362.9	198.9	6.3												1.5	0.0
COST 9	15.	1.56																		
LEFT UNCUT	20.	37.	64.8	6.6	269.3	583.2	44.1												3.4	0.0
COST 9	20.	1.56																		
LEFT UNCUT	25.	43.	79.2	8.2	216.6	938.7	100.0												6.0	0.0
COST 9	25.	1.56																		
LEFT UNCUT	30.	48.	89.2	9.4	185.7	1236.6	160.3												8.9	0.0
COST 9	30.	1.56																		
LEFT UNCUT	35.	52.	96.8	10.3	166.9	1489.0	220.1												12.1	0.0
COST 9	35.	1.56																		
LEFT UNCUT	40.	55.	102.7	11.0	154.4	1702.1	276.9												15.5	0.0
COST 9	40.	1.56																		
LEFT UNCUT	45.	58.	107.4	11.6	145.4	1882.5	329.7												19.1	0.0
COST 9	45.	1.56																		
COST 10	50.	6.10																		
HARVESTED	50.	60.	111.2	12.1	138.5	2036.3	378.1						111.2	12.1	138.5	2036.3	378.1	0.186	22.8	0.0
COST 1	0.	0.26																		
COST 2	0.	0.51																		
TRIAL 8 MAX HARV AGE					1	50.000	SITE INDEX			7	80.000									
COST 4	0.	18.37																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	20.	21.9	3.3	372.0	0.0	0.0												0.9	15.1
COST 9	10.	1.56																		
LEFT UNCUT	15.	37.	47.7	6.2	231.0	426.1	24.9												1.5	0.0
COST 9	15.	1.56																		
LEFT UNCUT	20.	49.	72.3	8.7	173.4	1031.5	98.9												3.4	0.0
COST 9	20.	1.56																		
LEFT UNCUT	25.	58.	89.5	10.8	140.6	1593.2	213.6												6.0	0.0
COST 9	25.	1.56																		
LEFT UNCUT	30.	64.	101.2	12.4	121.1	2061.5	368.3												8.9	0.0
COST 9	30.	1.56																		
LEFT UNCUT	35.	69.	109.9	13.6	109.1	2455.1	537.8												12.1	0.0
COST 9	35.	1.56																		
LEFT UNCUT	40.	73.	116.6	14.5	101.0	2783.8	679.8												15.5	0.0
COST 9	40.	1.56																		
LEFT UNCUT	45.	77.	121.8	15.3	95.2	3058.8	813.9												19.1	0.0
COST 9	45.	1.56																		
COST 10	50.	5.40																		
HARVESTED	50.	80.	125.8	15.9	90.7	3290.4	938.7						125.8	15.9	90.7	3290.4	938.7	0.285	22.8	0.0
COST 1	0.	0.26																		
COST 2	0.	0.76																		

Table 2.--Management level II. (cont.)

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 8	MAX HARV AGE				1	50.000	SITE INDEX			7	100.000									
COST 4	0.	23.37																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	25.	23.2	4.0	262.7	66.8	0.1												0.9	16.7
COST 9	10.	1.56																		
LEFT UNCUT	15.	46.	52.6	7.6	165.4	687.4	39.1												1.5	0.0
COST 9	15.	1.56																		
LEFT UNCUT	20.	61.	81.9	10.9	126.1	1587.3	143.3												3.4	0.0
COST 9	20.	1.56																		
LEFT UNCUT	25.	72.	102.7	13.5	103.3	2429.6	311.2												6.0	0.0
COST 9	25.	1.56																		
LEFT UNCUT	30.	80.	116.9	15.5	89.5	3129.8	542.4												8.9	0.0
COST 9	30.	1.56																		
LEFT UNCUT	35.	87.	127.2	17.0	80.9	3712.3	843.4												12.1	0.0
COST 9	35.	1.56																		
LEFT UNCUT	40.	92.	134.8	18.2	75.0	4191.7	1210.3												15.5	0.0
COST 9	40.	1.56																		
LEFT UNCUT	45.	96.	140.5	19.1	70.6	4586.8	1642.5												19.1	0.0
COST 9	45.	1.56																		
COST 10	50.	5.07																		
HARVESTED	50.	99.	144.8	19.9	67.3	4914.4	2128.1						144.8	19.9	67.3	4914.4	2128.1	0.433	22.8	0.0
COST 1	0.	0.26																		
COST 2	0.	1.01																		

Table 3.--Management level III.

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 8 MAX HARV AGE					1	50.000	SITE INDEX			7	60.000									
COST 4 0.15.20																				
NO DATA AT 0.																				
NO DATA AT 5.																				
LEFT UNCUT	10.	15.	37.0	2.4	1202.7	0.0	0.0												5.0	0.0
COST 9	10.	1.50																		
LEFT UNCUT	15.	28.	65.3	4.4	620.3	273.2	8.0												8.3	0.0
COST 9	15.	1.50																		
LEFT UNCUT	20.	37.	83.6	6.2	401.8	741.6	52.9												12.2	0.0
COST 9	20.	1.50																		
LEFT UNCUT	25.	43.	95.9	7.6	307.2	1136.2	114.8												16.4	0.0
COST 9	25.	1.50																		
LEFT UNCUT	30.	48.	104.5	8.6	257.2	1457.6	179.6												20.7	0.0
COST 9	30.	1.50																		
LEFT UNCUT	35.	52.	110.8	9.4	227.5	1721.2	241.8												25.1	0.0
COST 9	35.	1.50																		
LEFT UNCUT	40.	55.	115.6	10.1	208.0	1938.6	304.3												29.6	0.0
COST 9	40.	1.50																		
LEFT UNCUT	45.	58.	119.2	10.6	194.2	2119.6	364.6												34.1	0.0
COST 9	45.	1.50																		
COST 10	50.	7.09																		
HARVESTED	50.	60.	122.1	11.0	183.8	2271.6	423.4						122.1	11.0	183.8	2271.6	423.4	0.186	38.7	0.0
COST 1	0.	0.25																		
COST 2	0.	0.50																		
TRIAL 8 MAX HARV AGE					1	50.000	SITE INDEX			7	80.000									
COST 4 0.22.70																				
NO DATA AT 0.																				
NO DATA AT 5.																				
LEFT UNCUT	10.	20.	39.0	3.1	759.1	0.0	0.0												5.0	0.0
COST 9	10.	1.50																		
LEFT UNCUT	15.	37.	71.4	5.8	395.6	626.3	37.3												8.3	0.0
COST 9	15.	1.50																		
LEFT UNCUT	20.	49.	93.4	8.1	260.1	1336.8	144.2												12.2	0.0
COST 9	20.	1.50																		
LEFT UNCUT	25.	58.	108.3	9.9	200.7	1951.7	294.8												16.4	0.0
COST 9	25.	1.50																		
LEFT UNCUT	30.	64.	118.5	11.3	168.8	2453.1	449.9												20.7	0.0
COST 9	30.	1.50																		
LEFT UNCUT	35.	69.	125.8	12.4	149.6	2861.5	601.4												25.1	0.0
COST 9	35.	1.50																		
LEFT UNCUT	40.	73.	131.2	13.3	136.9	3194.4	751.5												29.6	0.0
COST 9	40.	1.50																		
LEFT UNCUT	45.	77.	135.2	13.9	127.8	3467.9	895.1												34.1	0.0
COST 9	45.	1.50																		
COST 10	50.	6.25																		
HARVESTED	50.	80.	138.2	14.5	120.9	3694.7	1032.5						138.2	14.5	120.9	3694.7	1032.5	0.279	38.7	0.0
COST 1	0.	0.25																		
COST 2	0.	0.75																		

Table 3.--Management level III. (cont.)

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 8	MAX HARV AGE				1.	50.000	SITE INDEX			7	100.000									
COST 4	0.	30. 20																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	25.	41.2	3.8	536.1	0.0	0.0												5.0	0.0
COST 9	10.	1.50																		
LEFT UNCUT	15.	46.	78.7	7.1	284.6	1028.4	65.6												8.3	0.0
COST 9	15.	1.50																		
LEFT UNCUT	20.	61.	105.8	10.1	191.1	2074.0	210.9												12.2	0.0
COST 9	20.	1.50																		
LEFT UNCUT	25.	72.	124.4	12.4	149.2	2995.2	432.1												16.4	0.0
COST 9	25.	1.50																		
LEFT UNCUT	30.	80.	137.0	14.1	126.2	3744.8	730.0												20.7	0.0
COST 9	30.	1.50																		
LEFT UNCUT	35.	87.	145.6	15.4	112.2	4348.2	1095.6												25.1	0.0
COST 9	35.	1.50																		
LEFT UNCUT	40.	92.	151.7	16.5	102.7	4832.2	1546.6												29.6	0.0
COST 9	40.	1.50																		
LEFT UNCUT	45.	96.	156.0	17.3	95.9	5222.8	1933.5												34.1	0.0
COST 9	45.	1.50																		
COST 10	50.	5.88																		
HARVESTED	50.	99.	159.1	17.9	90.7	5540.9	2215.6						159.1	17.9	90.7	5540.9	2215.6	0.400	38.7	0.0
COST 1	0.	0.25																		
COST 2	0.	1.00																		

Table 4.--Management level IV.

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	F/U	QUAL	H-BA
TRIAL 4 MAX HARV AGE					1	50.000	SITE INDEX			7	60.000									
COST 4	0.	15.87																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	15.	37.0	2.4	1202.7	0.0	0.0												5.0	0.0
COST 9	10.	1.56																		
LEFT UNCUT	15.	28.	65.3	4.4	620.3	273.2	7.7												8.3	0.0
COST 9	15.	1.56																		
LEFT UNCUT	20.	37.	83.6	6.2	401.8	741.6	52.6												12.2	0.0
COST 9	20.	1.56																		
COST 10	25.	3.34																		
THINNED	25.	43.	95.9	7.6	307.2	1136.2	114.5	70.1	8.3	185.7	889.5	95.5	25.8	6.2	121.5	246.7	12.3	0.050	16.4	0.0
COST 9	25.	1.56																		
COST 10	30.	2.14																		
THINNED	30.	48.	85.7	9.3	183.2	1190.3	150.6	70.2	9.8	138.4	1006.8	133.4	15.5	8.0	44.9	183.5	13.7	0.074	24.0	0.0
COST 9	30.	1.56																		
LEFT UNCUT	35.	52.	83.3	10.5	137.3	1278.2	191.5												31.1	0.0
COST 9	35.	1.56																		
COST 10	40.	2.39																		
THINNED	40.	55.	94.7	11.3	136.4	1563.6	263.8	70.1	12.0	92.6	1198.6	209.5	24.6	10.1	43.8	365.1	41.6	0.114	33.9	0.0
COST 9	40.	1.56																		
LEFT UNCUT	45.	58.	80.0	12.6	92.3	1384.0	262.0												40.3	0.0
COST 9	45.	1.56																		
COST 10	50.	4.74																		
HARVESTED	50.	60.	89.0	13.3	92.0	1601.8	331.5						89.0	13.3	92.0	1601.8	331.5	0.207	42.2	0.0
COST 1	0.	0.51																		
COST 2	0.	0.51																		
TRIAL 4 MAX HARV AGE					1	50.000	SITE INDEX			7	80.000									
COST 4	0.	23.37																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	20.	39.0	3.1	759.1	0.0	0.0												5.0	0.0
COST 9	10.	1.56																		
LEFT UNCUT	15.	37.	71.4	5.8	395.6	626.3	37.0												8.3	0.0
COST 9	15.	1.56																		
COST 10	20.	2.22																		
THINNED	20.	49.	93.4	8.1	260.1	1336.8	143.9	80.3	8.6	197.8	1192.0	119.4	13.1	6.2	62.3	144.8	5.3	0.037	12.2	0.0
COST 9	20.	1.56																		
LEFT UNCUT	25.	58.	105.3	10.0	193.5	1896.6	284.9												21.1	0.0
COST 9	25.	1.56																		
COST 10	30.	3.55																		
THINNED	30.	64.	125.8	11.0	190.5	2617.9	477.0	80.1	11.9	108.9	1744.8	310.7	45.8	10.1	81.6	873.1	108.4	0.124	26.0	0.0
COST 9	30.	1.56																		
LEFT UNCUT	35.	69.	97.0	12.8	108.0	2192.0	451.8												33.3	0.0
COST 9	35.	1.56																		
COST 10	40.	2.45																		
THINNED	40.	73.	111.9	13.8	107.3	2701.3	644.9	80.1	14.6	70.9	1986.8	477.7	31.9	12.7	36.4	714.5	115.9	0.162	36.3	0.0
COST 9	40.	1.56																		
LEFT UNCUT	45.	77.	92.9	15.5	70.7	2326.2	624.0												42.9	0.0
COST 9	45.	1.56																		
COST 10	50.	4.55																		
HARVESTED	50.	80.	104.5	16.5	70.5	2712.4	815.7						104.5	16.5	70.5	2712.4	815.7	0.301	45.1	0.0
COST 1	0.	0.51																		
COST 2	0.	0.76																		

Table 4.--Management level IV. (cont.)

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 4	MAX HARV AGE				1	50.000	SITE INDEX			7	100.000									
COST 4	0.	30.87																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	25.	41.2	3.8	536.1	0.0	0.0												5.0	0.0
COST 9	10.	1.56																		
LEFT UNCUT	15.	46.	78.7	7.1	284.6	1028.4	65.4												8.3	0.0
COST 9	15.	1.56																		
COST 10	20.	2.13																		
THINNED	20.	61.	105.8	10.1	191.1	2074.0	210.7	90.2	10.6	146.8	1811.4	171.7	15.6	8.0	44.3	262.6	18.0	0.069	12.2	0.0
COST 9	20.	1.56																		
LEFT UNCUT	25.	72.	122.2	12.5	143.7	2936.1	417.9												21.2	0.0
COST 9	25.	1.56																		
COST 10	30.	3.56																		
THINNED	30.	80.	149.1	13.9	141.6	4090.9	830.6	90.0	14.9	77.8	2562.4	438.3	59.1	13.0	63.7	1528.5	247.1	0.162	26.2	0.0
COST 9	30.	1.56																		
LEFT UNCUT	35.	87.	111.6	16.3	77.2	3290.1	757.2												33.4	0.0
COST 9	35.	1.56																		
COST 10	40.	2.43																		
THINNED	40.	92.	130.9	17.7	76.8	4097.5	1230.3	90.0	18.6	49.2	2881.8	788.2	40.9	16.5	27.6	1215.7	297.7	0.245	36.6	0.0
COST 9	40.	1.56																		
LEFT UNCUT	45.	96.	106.3	19.9	49.0	3431.4	1184.1												43.1	0.0
COST 9	45.	1.56																		
COST 10	50.	4.19																		
HARVESTED	50.	99.	121.3	21.3	48.9	4036.2	1656.2						121.3	21.3	48.9	4036.2	1656.2	0.410	45.4	0.0
COST 1	0.	0.51																		
COST 2	0.	1.01																		

Table 5.--Management level V.

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 8 MAX HARV AGE 1 50.000 SITE INDEX 7 60.000																				
COST 4 1.15.20																				
COST 6 1.14.50																				
COST 11 4.14.00																				
NO DATA AT 0.																				
NO DATA AT 5.																				
LEFT UNCUT 10.	13.	49.6	4.5	439.0	40.0	0.6													10.0	0.0
COST 9 10. 1.50																				
LEFT UNCUT 15.	25.	68.2	5.4	423.4	284.6	14.0													14.2	0.0
COST 9 15. 1.50																				
LEFT UNCUT 20.	34.	86.0	6.2	411.5	686.7	49.8													18.7	0.0
COST 9 20. 1.50																				
LEFT UNCUT 25.	42.	99.9	6.8	401.9	1134.0	98.5													23.4	0.0
COST 9 25. 1.50																				
LEFT UNCUT 30.	49.	110.3	7.2	393.7	1559.4	157.7													28.2	0.0
COST 9 30. 1.50																				
LEFT UNCUT 35.	53.	117.6	7.5	386.6	1935.2	223.1													33.2	0.0
COST 9 35. 1.50																				
LEFT UNCUT 40.	58.	122.6	7.7	380.2	2254.3	290.1													38.1	0.0
COST 9 40. 1.50																				
LEFT UNCUT 45.	61.	125.8	7.8	374.5	2518.9	356.3													42.9	0.0
COST 9 45. 1.50																				
COST 10 50. 8.00																				
HARVESTED 50.	64.	127.7	8.0	369.3	2734.5	420.5							127.7	8.0	369.3	2734.5	420.5	0.154	47.7	0.0
COST 1 0. 0.25																				
COST 2 0. 0.50																				
TRIAL 8 MAX HARV AGE 1 50.000 SITE INDEX 7 80.000																				
COST 4 1.22.70																				
COST 6 1.14.50																				
COST 11 4.14.00																				
NO DATA AT 0.																				
NO DATA AT 5.																				
LEFT UNCUT 10.	22.	70.0	5.4	439.0	232.4	7.7													10.0	0.0
COST 9 10. 1.50																				
LEFT UNCUT 15.	35.	97.5	6.5	423.4	826.2	57.5													15.0	0.0
COST 9 15. 1.50																				
LEFT UNCUT 20.	47.	124.0	7.4	411.5	1693.0	184.0													20.0	0.0
COST 9 20. 1.50																				
LEFT UNCUT 25.	57.	145.0	8.1	401.9	2606.2	354.1													25.0	0.0
COST 9 25. 1.50																				
LEFT UNCUT 30.	64.	160.6	8.6	393.7	3450.8	563.7													30.0	0.0
COST 9 30. 1.50																				
LEFT UNCUT 35.	70.	172.0	9.0	386.6	4186.2	780.0													35.0	0.0
COST 9 35. 1.50																				
LEFT UNCUT 40.	75.	180.0	9.3	380.2	4806.8	966.6													40.0	0.0
COST 9 40. 1.50																				
LEFT UNCUT 45.	79.	185.5	9.5	374.5	5321.8	1148.3													45.0	0.0
COST 9 45. 1.50																				
COST 10 50. 8.16																				
HARVESTED 50.	82.	189.1	9.7	369.3	5744.7	1319.0							189.1	9.7	369.3	5744.7	1319.0	0.230	50.0	0.0
COST 1 0. 0.25																				
COST 2 0. 0.75																				

Table 5.--Management level V. (cont.)

YIELD TABLE	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 8 MAX HARV AGE 1 50.000 SITE INDEX 7 100.000																				
COST 4 1.30.20																				
COST 6 4.14.50																				
COST 11 4214.00																				
NO DATA AT 0.																				
NO DATA AT 5.																				
LEFT UNCUT	10.	32.	99.1	6.4	439.0	713.9	25.9												10.0	0.0
COST 9 10. 1.50																				
LEFT UNCUT	15.	47.	134.3	7.6	423.4	1819.9	136.3												15.0	0.0
COST 9 15. 1.50																				
LEFT UNCUT	20.	61.	170.0	8.7	411.5	3360.4	462.0												20.0	0.0
COST 9 20. 1.50																				
LEFT UNCUT	25.	71.	198.3	9.5	401.9	4927.2	965.7												25.0	0.0
COST 9 25. 1.50																				
LEFT UNCUT	30.	80.	219.5	10.1	393.7	6347.6	1401.9												30.0	0.0
COST 9 30. 1.50																				
LEFT UNCUT	35.	86.	235.0	10.6	386.6	7570.1	1837.1												35.0	0.0
COST 9 35. 1.50																				
LEFT UNCUT	40.	92.	246.1	10.9	380.2	8595.8	2254.6												40.0	0.0
COST 9 40. 1.50																				
LEFT UNCUT	45.	96.	253.9	11.1	374.5	9445.3	2648.2												45.0	0.0
COST 9 45. 1.50																				
COST 10 50. 9.38																				
HARVESTED	50.	100.	259.3	11.3	369.3	10144.5	3017.8						259.3	11.3	369.3	10144.5	3017.8	0.297	50.0	0.0
COST 1 0. 0.25																				
COST 2 0. 1.00																				

Table 6.--Management level VI.

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	M-BA
TRIAL 4 MAX HARV AGE 1 50.000 SITE INDEX 7 60.000																				
COST 4 1.15.20																				
COST 6 1.14.50																				
COST 11 4.14.00																				
NO DATA AT 0.																				
NO DATA AT 5.																				
LEFT UNCUT	10.	13.	49.6	4.5	439.0	40.0	0.6												10.0	0.0
COST 9	10.	1.50																		
LEFT UNCUT	15.	25.	68.2	5.4	423.4	284.6	16.0												14.2	0.0
COST 9	15.	1.50																		
COST 10	20.	2.07																		
THINNED	20.	34.	86.0	6.2	411.5	686.7	49.8	70.2	6.7	311.5	594.5	47.1	15.7	5.4	100.0	92.2	2.8	0.031	18.7	0.0
COST 9	20.	1.50																		
COST 10	25.	2.15																		
THINNED	25.	45.	90.5	7.4	303.8	1145.7	111.8	70.1	8.0	218.3	935.0	99.1	20.3	6.6	85.6	210.7	11.5	0.055	27.3	0.0
COST 9	25.	1.50																		
COST 10	30.	1.78																		
THINNED	30.	52.	86.4	8.6	215.1	1337.6	165.8	70.1	9.1	164.6	1122.6	148.9	16.3	7.7	50.5	215.0	15.0	0.070	34.8	0.0
COST 9	30.	1.50																		
LEFT UNCUT	35.	57.	83.7	9.7	163.1	1476.3	222.3												41.7	0.0
COST 9	35.	1.50																		
COST 10	40.	1.97																		
THINNED	40.	61.	95.3	10.4	162.0	1851.0	319.3	70.0	11.1	111.6	1414.1	255.4	25.2	9.6	50.4	436.9	48.6	0.111	44.2	0.0
COST 9	40.	1.50																		
LEFT UNCUT	45.	64.	80.2	11.5	111.2	1661.8	323.5												50.4	0.0
COST 9	45.	1.50																		
COST 10	50.	3.70																		
HARVESTED	50.	67.	89.3	12.2	110.8	1953.0	419.9						89.3	12.2	110.8	1953.0	419.9	0.215	52.1	0.0
COST 1	0.	0.50																		
COST 2	0.	0.50																		
TRIAL 4 MAX HARV AGE 1 50.000 SITE INDEX 7 80.000																				
COST 4		1.22.70																		
COST 6		1.14.50																		
COST 11		4.14.00																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	22.	70.0	5.4	439.0	232.4	7.7												10.0	0.0
COST 9	10.	1.50																		
COST 10	15.	2.12																		
THINNED	15.	35.	97.5	6.5	423.4	826.2	57.5	80.2	7.0	324.4	712.9	46.8	17.3	5.7	99.0	113.3	4.4	0.039	15.0	0.0
COST 9	15.	1.50																		
COST 10	20.	2.70																		
THINNED	20.	51.	115.2	8.2	310.6	1751.9	201.0	80.1	9.0	198.1	1290.7	130.7	35.2	7.6	112.4	461.2	35.4	0.077	25.0	0.0
COST 9	20.	1.50																		
LEFT UNCUT	25.	61.	106.4	10.0	193.4	2060.9	326.6												33.8	0.0
COST 9	25.	1.50																		
COST 10	30.	2.67																		
THINNED	30.	68.	127.7	11.1	190.0	2896.8	579.0	80.0	12.0	110.4	1911.7	376.3	47.6	10.5	79.6	985.0	131.4	0.133	38.5	0.0
COST 9	30.	1.50																		
LEFT UNCUT	35.	74.	97.5	12.8	109.5	2436.8	552.0												45.5	0.0
COST 9	35.	1.50																		
COST 10	40.	1.93																		
THINNED	40.	79.	112.9	13.8	108.7	3040.9	805.2	80.0	14.6	72.9	2222.7	595.8	32.8	13.0	35.8	818.3	148.3	0.181	48.3	0.0
COST 9	40.	1.50																		
LEFT UNCUT	45.	83.	93.2	15.3	72.6	2631.0	782.4												54.6	0.0
COST 9	45.	1.50																		
COST 10	50.	3.36																		
HARVESTED	50.	87.	105.1	16.3	72.4	3096.4	1037.0						105.1	16.3	72.4	3096.4	1037.0	0.335	56.5	0.0
COST 1	0.	0.50																		
COST 2	0.	0.75																		

Table 6.--Management level VI. (cont.)

YIELD TABLE

	AGE	HT	STAND BEFORE CUTTING BA	DBH	TREES	VOLUME	VALUE	STAND LEFT BA	DBH	TREES	VOLUME	VALUE	STAND CUT BA	DBH	TREES	VOLUME	VALUE	P/U	QUAL	H-BA
TRIAL 4	MAX HARV AGE				1	50.000	SITE INDEX			7	100.000									
COST 4	1.	30.20																		
COST 6	1.	14.50																		
COST 11	4.	14.00																		
NO DATA AT	0.																			
NO DATA AT	5.																			
LEFT UNCUT	10.	32.	99.1	6.4	439.0	713.9	25.9												10.0	0.0
COST 9	10.	1.50																		
COST 10	15.	3.32																		
THINNED	15.	47.	134.3	7.6	423.4	1819.9	136.3	90.1	8.4	258.0	1306.8	84.6	44.2	7.0	165.4	513.2	27.3	0.053	15.0	0.0
COST 9	15.	1.50																		
COST 10	20.	2.77																		
THINNED	20.	65.	135.2	10.0	247.3	2917.3	333.5	90.1	10.8	152.5	2041.0	200.6	45.1	9.3	94.8	876.3	72.1	0.082	25.0	0.0
COST 9	20.	1.50																		
LEFT UNCUT	25.	76.	123.7	12.3	149.0	3226.6	491.7												33.7	0.0
COST 9	25.	1.50																		
COST 10	30.	2.72																		
THINNED	30.	85.	151.7	13.8	146.5	4504.6	979.6	90.0	14.7	81.3	2794.1	522.7	61.7	13.2	65.3	1710.5	285.8	0.167	38.6	0.0
COST 9	30.	1.50																		
LEFT UNCUT	35.	92.	112.3	16.0	80.6	3595.3	912.9												45.5	0.0
COST 9	35.	1.50																		
COST 10	40.	1.93																		
THINNED	40.	97.	132.2	17.4	80.1	4501.2	1477.1	90.3	18.3	52.0	3155.3	957.4	42.0	16.5	28.1	1345.9	353.9	0.263	48.3	0.0
COST 9	40.	1.50																		
LEFT UNCUT	45.	102.	106.9	19.5	51.8	3772.7	1452.9												54.5	0.0
COST 9	45.	1.50																		
COST 10	50.	3.15																		
HARVESTED	50.	106.	122.3	20.8	51.6	4455.1	2052.2						122.3	20.8	51.6	4455.1	2052.2	0.461	56.5	0.0
COST 1	0.	0.50																		
COST 2	0.	1.00																		

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GPO 861-654